DDL Working Papers

WP1 Dynamic Lighting Concepts, WP2 Dynamic Lighting, Health and Wellbeing Potentials, WP3 Percieved spatial distribution of light in a dynamic context

Hansen, Ellen Kathrine; Linnebjerg, Sofie

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A terminological study

- An analysis that investigates different terminologies developed for various concept of dynamic lighting systems - how they function and what they do or will do under a certain circumstance and why they function or react as they do.
- An overall comparison: similarities and differences
- This provides an overview of the field of dynamic lighting in different areas of research and seeks to offer material for vocabulary and mapping of the discipline

State-of-the-Art
- Technology has created endless possibilities for designing lighting that varies over time. What dynamic structures are being investigated? And what are the biggest potentials and pitfalls?
- Subjective vs objective health (visual versus non-visual effects)
- Recommendations for future research of dynamic lighting design

State-of-the-Art
- The perceived distribution of lighting has shown to affect our subjective health and wellbeing. What has research so far uncovered of spatial qualities of lighting?
- Recommendations for investigating the spatial dimension of lighting design

Working Paper 1

Dynamic Lighting Concepts

1. Introduction

1.1.Dynamic

LED technology and control systems can provide any quality and quantity in any composition at any moment of the day. This offers unprecedented possibilities for flexible, dynamic user-centred lighting, which can be optimally tuned to support humans' visual and non-visual needs. Furthermore, the light technology has undergone a digitalization, allowing intelligent control and adaptive behaviour, that reacts to a wide range of input. The lighting has become dynamic in every thinkable way.

1.2.Health and wellbeing potential

The importance of dynamic light to support health and well-being has been more and more recognized [Hansen et al., 2017]. Humans has through many years of evolution adapted to the changing light of the sun, varying through the day, seasons and under various weather conditions, creating a multitude of light settings. Humans live in interaction with this dynamic light and consider it as a natural part of our world [Mathiasen, 2015]. Furthermore, it has by the recent discovery of intrinsically photosensitive retinal ganglion cells (ipRGC) in 2002 [Berson et al., 2002] become apparent, that light, beside serving a purpose of enabling visual orientation, also are influencing circadian master pacemaker (body clock), affecting, alertness and attention and as such our health and wellbeing on a biochemical level [ibid.] – and as humans spend more than 90 % of the time inside a build environment [Klepeis et al., 2001] the daylight intake in our buildings is not always optimal to meet human needs for dynamic light [Hansen et al., 2017]. Lighting can be considered a multidimensional design element [Hansen, 2013] due to its influence on both human psyche and physic, it has been highlighted that in order to investigate, test and evaluate dynamic lighting designs effect on health and wellbeing, it is required to apply a holistic approach incorporating different disciplines, using both qualitative and quantitative data to get a deeper understanding of our lighting environment [Sen et al. 2017, Mathiasen 2015; Hansen, 2012]. Namely when the atmosphere of a space "fuses and heightens the sensory experience", and draws on philosophical as well as neurological resources [Pallasmaa, 2013]. In order to investigate lighting holistically, it is necessary to combine and integrate knowledge from different disciplines.

1.3. Dynamic lighting for helath and wellbeing

In research this subject is still relatively new. Even so, many concepts of dynamic lighting has been developed within various scientific fields. The objective of this working paper is to investigate the many concepts of 'dynamic lighting for health and wellbeing', and through a terminological analysis of all these concepts, unfold this complex subject and provide an overview for future research.

1.4.Looking at the whole through the units

An analysis is to look for the meaning of things, to look for the objectives, discover the fundamental elements to uncover how things function and what they do or will do under a certain circumstance and why they function or react as they do.

According to Concise Oxford Dictionary, analysis is "Resolution into simpler elements by analyzing (opp. synthesis); statement of result of this" (1976, ed. J. B. Sykes). In Oxford Dictionary of Philosophy, analysis is defined as "The process of breaking a concept down into more simple parts, so that its logical structure is displayed" (1996, by Simon Blackburn).
Thus, this working paper will break down the subject 'dynamic lighting for health and wellbeing', through the analysis of all concepts developed or studied in research and break down all concepts through the analysis of 'objective', 'impetus', 'field of science', 'lighting variables', 'human effects', 'function', 'context', target group'. In order to search, evaluate and select concepts to further pursuit in analysis, methodical considerations had to be made.

2. Method

2.1.Methodical considerations

What do you do, when the subject investigated is complex, cross disciplinary, relatively young and in rapid development? In terms of searching for the most important paper on a given subject it is the predominantly assumption, that the review method should employ the most explicit and meticulous search strategy as possible. This assumption has been elaborated by Greenhalgh and Peacock, who distinguished between "simple" and "complex" evidence (1). Aforementioned method might be the most effective in terms of simple and quantitative studies, Greenhalgh and Peacock exemplifies: "In systematic reviews of clinical treatments, most high quality primary studies can be identified by searching four standard electronic databases". But what Greenhalgh and Peacock adds to this is: "In systematic reviews of complex and heterogeneous evidence (such as those undertaken for management and policymaking questions) formal protocol-driven search strategies may fail to identify important evidence" (ibid., p. 1065).

As alternatives to the systematic reviews for investigating more complex and heterogeneous subjects, such as present subject: 'dynamic lighting for health and wellbeing', Greenhalgh and Peacock studies "sowballing" and "personal knowledge". Snowballing is a review method, where the material is emerging as the study is unfolded. Practically it can be tracking of either references or citations, and can be done either systematically through electronic search or by tedious tracking of interesting references and by judgement decide to follow up on these or not. Greenhalgh and Peacock concludes, that ""Snowball" methods such as pursuing references of references and electronic citation tracking are especially powerful for identifying high quality sources in obscure locations" (ibid.).
Even the very informal approach 'personal' knowledge can "substantially increase the yield and efficiency of search efforts" (ibid.), by browsing through other experts in the network, or being alert to occurring interesting material.

Greenhalgh and Peacock test the effectiveness and efficiency of all three search methods, in a comprehensive search including more than 6000 electronic abstracts. The result

1. *"Electronic searching, including developing and refining search strategies and adapting these to different databases, took about two weeks of specialist librarian time and yielded only about a quarter of the sources—an average of one useful paper every 40 minutes of searching.*

2. *It took a month to hand search a total of 271 journal-years, from which we extracted only 24 papers that made the final report—an average of one paper per nine hours of searching.*

3. *Overall, the greatest yield was from pursuing selected references of references. It was impossible to isolate the time spent on reference tracking since this was done in parallel with the critical appraisal of each paper.*

4. *Electronic citation tracking of selected papers took around a day in total and uncovered many important, recent sources, including five systematic reviews (three of which were not identified by any other method) and 12% of all empirical studies—around one useful paper for every 15 minutes of searching" (ibid.).*

Thus, Greenhalgh and Peacock points towards the gains of employing both systematic review that are purely protocol driven with supplementary methods, such as references tracking ("snowballing"), may be both more effective and efficient to uncover important sources that otherwise wouldn't have been found, no matter how many databases are searched with a protocol.

This working paper sets out to investigate 'dynamic lighting for health and wellbeing', a subject that is investigated within many scientific fields and disciplines, that often possesses their own terminology. This engenders a complex and heterogeneous field, that hardly can be mapped and analysed through systematic literature review, without commonly used terms. This working paper have therefore employed supplementary search methods, in order to uncover more odious papers from more obscure journals, to achieve a mapping of investigated subject, more in the width than in the depth.

2.2.Selection process

The objective of the literature search phase, was to uncover as many, and different concepts/terms used for dynamic lighting for health and wellbeing. The procedure for literature searching in this working paper has thus been alternating between using systematic review and reference tracking, starting with a protocol for the keywords 'dynamic', 'lighting', 'health', 'wellbeing' in broad database platforms (Scopus, Springer, Sage, Elsevier, Proquest). Hereafter, interesting references was scrutinized and alternative key words (dynamic lighting concepts for health and wellbeing). The final result from the search phase is 56 concepts/terms that has been used to describe a dynamic lighting concept for health and wellbeing. After systematic reviewing literature for all 56 concepts, 30 concepts have been discharged based on three criteria; a) the scientific validity of the material describing the term/concept[1] b) whether the term/concept is used more than once in the material c) the dynamic quality of the term/concept (elaborated in 2.3.1).

2.3.Concepts

Selected concepts:

1. Adaptive Lighting Control (ALC)
2. Affective Ambience (AA)
3. Ambient Intelligent Lighting (AIL)
4. Ambient Lighting Assistance (ALA)
5. Biological Active Light (BAL)
6. Candlelight-style OLED (CSO)
7. Circadian Lighting (CL)
8. Circadian Healthy Light (CHL)
9. Cycled Lighting (CL)
10. Dawn Simulated Lighting (DSL)
11. Drug Light (DrL)
12. Dynamic Lighting (DyL)
13. Dynamic Lighting System (DLS)

[1] Peer-reviewed articles, reports produced by research projects or editorials by reputable researchers

14. Enriching Lighting Design (ELD)
15. Healthy Lighting (HL)
16. Human-Centric Lighting (HCL)
17. Light-Dark Cycle (LDC)
18. Light Pulse (LP)
19. Light Therapy (LT)
20. Natural Lighting System (NLS)
21. Natural Light Reproduction System (NLRS)
22. Personalized Control (PC)
23. Phototherapy (Pt)
24. Pulsating Lighting (PL)
25. SmartHeliosity (SH)
26. Smart Lighting (SL)

Deselected concepts:

27. 24 hour lighting scheme
28. Action Spectrum Lighting
29. Ambient Lighting
30. Biological friendly lighting
31. Biomimetic Lighting /biomimicry Lighting
32. Biophilic Light
33. Changing Light
34. Circadian – Aware Lighting
35. Day night recycled light
36. Daylight Boosting (/mood-boosting daylight)
37. Daylight harvesting
38. Diurnal light variation
39. Flicker (/flickering lighting design/fire flicker)
40. Heliotherapy
41. Intelligent lighting
42. Interval Lighting/individualized lighting
43. Light harmony
44. Light over Time
45. Light patterns
46. Light phases
47. Lighting profiles
48. Melanopic Light Intensity (/ Melanopic Light Variation/ Melanopic Illumination / “Melanopic” Spectral Efficiency Function / Melanopic-Weighted Irradiance / Melanopic Lux (metric))
49. NICU Lighting
50. Personalised Intelligent Lighting Control System (PILCS), research project
51. Rhythmic Light (/Light Rhythm / Rhythmical Light / Bio-Rhythmic Light)
52. Seasonal lighting
53. SunLike
54. Tuneable LED lighting system
55. Variable lighting
56. Weather Dependent Light /(Weather Conditioned Light)

2.3.1. The dynamic quality

Present working paper is an attempt to get closer to describe the phenomenon ‘dynamic lighting’ through a mapping of the many varying interpretations of dynamic lighting concepts in research. But to get started, an initial framing has been made, and constantly evolved throughout the study. The initial framing of the ‘dynamic quality’ is based on physics definition:

“Dynamic is in the concerned with the study of forces and torques and their effect on motion
1(of a process or system) characterized by constant change, activity, or progress.
1.1Physics Relating to forces producing motion.
Often contrasted with static” (Oxford Dictionary)

In order to evaluate the ‘dynamic quality’ of a lighting concept, one has to identify the impetus for the movement – the force that starts the dynamic motion/change/development. Which more or less renders ‘dynamic markings’ as relative. For instance, could the daily use of a classical lighting switch (on and of) be seen as a dynamic lighting system? Couldn’t any artificial lighting in a space with windows be seen as dynamic, if the ever-changing daylight are included in the total lighting environment and create endless compositions and expression depending on weather, time of day and season. Couldn’t the flicker of an artificial light source be considered a dynamic? As lighting is a constant flux of particles in motion, with a certain speed, wavelength and direction, it can be said that lightings very nature is dynamic. Which almost brings one to question whether any lighting is ever static?

One could also look at the way ‘dynamic’ is used in music: “*Dynamics are one of the <u>expressive elements</u> of music. Used effectively, dynamics help musicians sustain variety and interest in a musical*

performance, and communicate a particular emotional state or feeling" (wiki). In this case, dynamic would be a visually experienced 'expression' of light.
The final framing of 'dynamic quality' is in this working paper quite open, and builds on the understanding of a) a diurnal variance, that b) are visibly perceivable and c) considers more than the preference and a manual switch as an impetus (the force to change/move/develop).

3. Results and discussion

3.1.Non-visual vs. visual effects

Many of the concepts investigated often aims at exerting more than one effect on the human condition. Not rarely both non-visual and visual effects respectively objective and subjective approaches. When comparing the 26 concepts and their intended effect on human condition as either visual effects or non-visual effect they are distributed as following:

Variety of categories:	29 categories (67.5 %) Non-visual effects 14 categories (32.5 %) Visual effects
Variety of categories:	27 categories (77.1 %) Non-visual effects (disregarded method) 11 categories (22.9 %) Visual effects (disregarded method)
Preference of methods:	66 times (57.9%) that objective effects was investigated 48 times (42.1%) that subjective effects was investigated
Frequency of investigation	75 times that non-visual effects are investigated (65.8 %) 39 times that visual effects are investigated (34.2 %)

If we take a look at the variety of the number different types of effects (categories) that are investigated among the concepts, there are approximately twice as many different types of non-visual effects, that are investigated, compared with the number of different types of visual effects. When not distinguishing between objective/subjective effects, the difference become even bigger. Likewise, there are approximately twice a big frequency of investigated non-visual effects among the 26 analysed concepts compared to the frequency of investigated visual effects. Even if we look at the most frequently investigated effect among respectively non-visual / visual effect: 'Entrainment of circadian system' (non-visual, 10 incidents) / 'perception' (visual, 8 incidents).
A conclusive remark on the human effects of the concepts analysed is, that there is a remarkable greater interest in non-visual effects compared to visual effects. Method wise, there is an approximately even use of objective and subjective measures. 42.2% of the concepts uses both objective and subjective methods. 34.6% of the concepts are investigating both visual and non-visual effects.

3.2.The role of daylight

During the analysis of the concepts, it became apparent, that daylight was an interesting component, that significantly differentiated the concepts. Most of the concepts are relating to daylight, but in very different ways and on very different levels. I have post analysis attempted to formulate various categories of relationship to the component 'daylight':

A.	**An impetus**:	An impetus for the dynamic of the lighting
B.	**An inspiration**:	The inspiration for imitation (either visually or physically)
C.	**An equal:**	Considered an equal component in the total lighting environment
D.	**Inadequate:**	The premise where artificial lighting would have to partly compensate
E.	**Not accessible**:	The premise where artificial lighting would have to replace

A.: A third among the investigated concepts are in different degrees employing daylight as the impetus for the dynamic lighting system. Such as 'Healthy Lighting' (HL), that adjust the amount of light based on the amount of daylight. "Daylight, including high intensities and natural dynamics, is an important light source for healthy lighting. However, no building can be lit by daylight alone because daylight is not 'reliable' according to the weather, the time of day or the time of year. Generally, it does not even reach all areas in a building and sometimes the intensity is too low." (2, p. 7). The daylight is here recognised as 'important' but 'unreliable'.

B.: Concepts such as "Dawn Simulated Lighting" (DSL), are using the phenomenon (and sometimes the proximity to the physical characteristics) of daylight, as an inspiration to the dynamic lighting design. But, in all of the three DSL articles, that has been selected and scrutinized, daylight is not addressed explicitly (3–5).

C.: 'Adaptive Lighting Control' (ALC) and Enriching Lighting Design (ELD) are the only concepts, considering dynamic artificial light and the incoming daylight as equally important components of the total lighting environment. By this, it is meant that, to some extent, architectural considerations are included to 'design' the optimal incoming daylight to complement electrical lighting. Hence, both daylight AND electrical light are designed to form one total lighting environment to enhance human health and wellbeing: "A special focus is on solutions that integrate daylight as a formative parameter of the adaptive lighting control." (3, p. 5); "It is important to balance daylight within the space and the best way to accomplish this is to use a minimum of two sources of daylight, preferably from more than one direction […]" (7, p. 195). Both are relatively new niche concepts.

D.: Concepts that aims at e.g. shift workers or inhabitants of high altitudes, are considering the daylight rhythm as inadequate to meet the biological need. Concepts such as 'Biological Active Lighting' (BAL): "[…] uses artificial light to expand daylight to constant length the year round, one may assume that the human environment is without seasonal time cues and that social influences may be of more importance." (4, p. 83).

E.: Concepts such as 'Natural Light Reproduction System' (NLRS), are addressing situations where daylight isn't accessible to humans or humans who can't access outdoor. For instance the concept Ambient Lighting Assistance (ALA) for elderly "Besides, with advanced age, many people suffer from reduced mobility and thus are limited in their outdoor activities or may even become home-bound. Lack of daylight can be counter-acted by increased illumination to prevent seasonal depression or sleep disturbances.". Other examples includes humans who occupy rooms without windows, rooms below ground level, etc.: "in windowless space such as underground space where there is no natural light, it is necessary to actually measure and analyze natural light characteristics that would change depending on the daily, monthly, and seasonal cycles of natural light." (5, p. 2).

Only concepts, whose functionality are concerned with task- or effect lighting are not concerned with daylight. Concepts such as 'Personalized Control' (PC) and 'Affective Ambience' (AA).
A concluding remark: investigated concepts are often related to daylight, but varies from a superficial inspiration to a deep integration in a holistic lighting design. Among the 26 investigated concepts, 30.8% employs daylight as an impetus for variation on various levels. Only two concepts (7.7%) operates with a total lighting environment that equally addresses both daylighting and electrical lighting.

3.3.Three rhythms

In continuation of how dynamic lighting relates to daylight, it is interesting to look at the three biggest 'Impetus' for dynamic in the analysis: 'Circadian biological rhythm' (36,4%), 'The circadian solar cycle' (24,2%), 'Social working rhythm' (15,2%) and the fact, that they all represent a rhythm:

Three rhythms:

I. The human body's circadian system
II. The circadian solar cycle
III. The social diurnal rhythm

Where the 'human body circadian system' (HBCS), powered by a circadian pacemaker in the suprachiasmatic nucleus of the hypothalamus (SCN) synchronizes many rhythmic processes such as hormone secretion, skin temperature, heart rate, and the sleep-wake cycle (10). This rhythm is entrained by the 'circadian solar cycle' (CSC) that allows for synchronization of psychological and physiological processes, and can vary depending on altitude. The HBCS can further be altered with self-employed electrical lighting patterns in connection with our 'social diurnal rhythm' (SDR) in a 24/7 society (11). And, as life in a 24/7 society relies on the use of artificial lighting indoor – especially in the evening (ibid.), studies have concluded that this sometimes 'overrules' the CSC synchronization and the phenomenon are sometimes referred to as 'social jetlag' (misalignment of biological and social time) (12). There is a broad acknowledgement of the misalignment of these three rhythms is problematic on many levels. What is interesting, is that widely different approaches are taken to this issue. It seems that concepts that are concerned with the alignment of these three rhythms either attempts to get SDR close to the CSC or get HBCS adjusted to the SDR. One example to illustrate this could be blue light and the two concepts 'Drug Lighting' and Candlelight-style OLED, where the first concept <u>utilizes blue light</u> and the doping effect to advance the HBCS to SDR (13), whereas Candlelight-Style OLED <u>omits blue light</u> in order to allow HBCS to adjust to CSC (14). In relation to the misalignment between the three rhythms, I propose the division of dynamic lighting concepts as a facilitator to either <u>enforce</u> or to <u>modify</u> the 'natural' rhythm (HBCS). Further exemplification would include Circadian Healthy Lighting, that likewise addresses the three rhythms, and the overlap/gaps between. In this study they are referred to as the 'internal time', determined by the mid sleep time, and the 'external time', determined by the interaction between the daylight rhythm and the cultural diurnal rhythm imposed by working schedule. CHL argues, that it theoretically should be possible to synchronize between internal and external circadian rhythms, to benefit the modern human lifestyle, with nocturnal activity/work/late chronotypes, but advances with presenting current knowledge that proves, that people living in synchrony with the daylight rhythm have lower risks of: "*several health impairments, such as metabolic syndrome [11,116], cardiovascular diseases [117], cognitive impairments [118] and a higher incidence of breast cancer [68,69] among others."* (9, p. 14). CHL clearly are <u>skeptical about altering the natural rhythm</u> of the human body circadian system. Another example is 'Dynamic Lighting' (DL) that addresses the consequences of 24/7 society and modern working lifestyle (Stress and attention fatigue) and proposes that a protocol with periods with increased lighting level can be used strategically to alter normal natural rhythm to suit traditional office work. DL is, in reviewed articles, testing whether revitalizing bright lighting in the morning and after lunch can affect the hormonal rhythm and improve performance and alertness throughout the day (12, p. 848). Hence, DL is concerned witch modify HBCS to suit SDR, and allow people to wake up before natural sleep-wake cycle and furthermore eliminate natural 'post lunch dip' (16).

So even though the concepts target very different human effects (sleep, stress, performance etc.), and even though the means varies greatly from "ambience" (subjective, visual effects) to "drug effect" (objective, non-visual effect), common to them all is the acknowledgement of the misalignment between the HBCS, CSC and SDR - disregarded scientific field, methods and context.

3.4.Umbrella concepts and niche concepts

Some concepts seem to overlap – or one umbrella concept seem to contain many niche concepts. Thus, 'Dynamic Lighting' (DL) are one of the umbrella concepts, that shares many qualities with 'Pulsating Lighting' (PL) along with Healthy Lighting (HL) and Human Centric Lighting (HCL). Likewise, are Light Therapy (LT) containing the concept 'SmartHeliosity' (SH), 'Phototherapy' (Pt) and Dawn Simulated Lighting (DSL).

4. Conclusion

The analysis of 26 concepts of 'Dynamic lighting for health and wellbeing' that has been developed or studied in academia has revealed, that it is a broad and diverse research field, that is studied within many different scientific disciplines. Nevertheless, there are a number of tendencies within this research field:

I.: Generally, a significantly interest in investigating the non-visual effects on health and wellbeing, using objective methods compared to visual-effects, using subjective methods. This finding is supported by a similar review of dynamic lighting in schools, by Hansen et al. (17). This could maybe also partly be explained, by the fact that many of the concepts explicitly address, from 2002 and post hence, that visual ergonomic has been thoroughly investigated and therefore qualities such as 'visual acuity', 'visual performance' and 'glare' have been omitted in many of the more recent developed concepts. In regards to methods, 46,2% of the concepts employ both objective and subjective measures and 46.1% of the concepts investigates both non-visual and visual effects.

II.: Daylight is an interesting component in dynamic lighting for health and wellbeing. There is among the analysed concepts a common acknowledge of daylight as the optimal light source for humans. Apparently, there are no statistical covariates among the other categories (objective, impetus, function, etc.). It has in the discussion been proposed, that daylight can play five different roles in the concepts for 'dynamic for health and wellbeing': An impetus; An inspiration; An equal component; Inadequate; Not accessible. Only two concepts (ALC and ELD) are designing both daylight and electrical lighting.
For future research in dynamic lighting for health and wellbeing, there is an interesting potential in looking more into the dynamic interplay between architectural lighting and electrical lighting to

enhance health and wellbeing. Same suggestions are proposed by Volf: “Can the artificial lighting – and the interplay between natural and artificial lighting – be enhanced and better integrated in the architecture?” (18).

III.: the most common impetus for the analysed concepts are the three rhythms: the human body’s circadian system, the circadian solar cycle. the social diurnal rhythm and the misalignment between these mechanisms. Based on this analysis it has been proposed, that the concepts concerned with these rhythms, employs artificial lighting to either <u>enforce</u> or to <u>modify</u> the ‘natural’ rhythm (HBCS).

Additionally:

IV.: Dynamic lighting for health and wellbeing are primarily designed as the general lighting environment 61.5%, compared to e.g. light effect (19.2%) and treatment (27.0%).
V.: The analysis of the publishing year of articles reviewed suggest an increased development of new niche concepts after the discovery of the photoreceptor ipRGC in 2003 by scientist David Berson.

5. Literature

Applied after ‘concept one-pagers’.

6. Appendix

1. Overview of concept analysis
2. Overview of all material reviewed: selected and discharged concepts and references

Dynamic lighting concepts for health and wellbeing

One-pagers

Concept:

Adaptive Lighting Control (ALC)

Published:
2017
Kjell Yngve Petersen et al.

Article:
Energy optimization through adaptive lighting control (EAL)

Field of science
Mixed disciplines: Architecture, It-technology
Integrating: Environmental aesthetics (sub-field of philosophical aesthetics)

Objectives
Wellbeing, Energy efficiency

Key terms:
Ambience
"The lighting situation that does not appear as something clearly illuminated or luminous, nor does it recedes in the background, that it becomes part of the general environment. The ambient light is clearly apparent, it gives light and shape to the room and those present, but is not clearly distinguishable as individual elements." (1, p. 18, transl.)

- The light environment in its flexible variation, which results from the combination of light sources.
- Involves light incidences from sun and sky light, street and, for example, car lights, and the light reflected from the city's other elements.
- Involves light reflections in materials and emphasizes shapes in space.
- Determined by the interior design and the human experience in daily activities

Lived life
"Needs are complex and varied, dependent on contexts more than absolute values. The adaptive optimization strategy in light design will be able to handle solutions, There is a negotiated connection of the ambient in a combined perspective of architectural design and building management, users' practice and experience, and intelligent and balanced consumption of energy resources." (ibid., transl.).

Human centric sustainability
"Adjustment of energy resources: Central to the adaptive light in the EAL project is also the carefully considered and relevant use of energy resources better can be achieved by providing increased room for flexibility for individual solutions and continuous customization, with a pronounced sense of being able to shape their surroundings as needed." (ibid., p. 19, transl.)
Adaptive lighting control operates with three sustainability areas: 1. architectural design and building management, 2. users' life practice and experience, 3. intelligent and balanced consumption of energy resources.

Target group/ Application:
No specific target group. Tested in office settings

Fundamental elements (variables)

Light:	Correlated colour temperature, intensity, architectural quality
Impetus:	Individual wishes, individual needs, daylight variations, spatial design
Human effect:	Subjective behaviour, subjective preference and subjective perception

The dynamic system
"Adaptive lighting makes it possible for the users to experience themselves as active participants in the configuration of each unique situation, and thereby facilitate a holistic balance between energy-optimisation, wellbeing and architectural design that is experienced as meaningful in the everyday life" (ibid., p. 7)

- Adapts to individuals wishes and needs (customization – active driver of the dynamic)
- Adapts within a framework of architectural lighting design (architectural quality)
- Adapts to daylight
- Takes energy consumption into account)

Everyday lighting and 'lighting-as- a-service' environments:
The IoT connected control system integrates user scenarios, daylight variations and architectural qualities in the design

"It is a key assumption in the EAL project that, instead of servicing specific solutions by monitoring and scenario control, one can advantageously establish an expanded scope for a multitude of possible solutions."
"Solutions that are all designed as qualitative outcomes within the design space, but as a starting point open to what the situation promotes and how the individual user chooses to shape their lighting environments" (ibid., p. 18, transl.)

Concept:
Affective Ambience (AA)

Published:
2014

Article:
Affective ambiences created with lighting for older people

Field of science:
Human technology interaction

Objective:
These ambiences not only satisfy visual needs, but may also improve people's well-being, creating a pleasant, relaxing ambience to counteract anxiousness and a pleasant, activating ambience to counteract sadness.

Key terms:
Operationalisation of affective ambience
"Fifteen professional lighting designers were asked to provide information on how they would design four specific affective ambiences having a young population in mind." (2, p. 862)

Affective ambience
Affective ambiences, using the psychological effects of (coloured) lighting. To evaluate the perception of these ambiences, we rely on the concept of atmosphere.23 Atmosphere does not represent the affective state of a person, but rather the affective state of an environ- ment, and is known to be almost immediately recognized." (ibid., p. 860)

Target group/ Context:
Elderly people, care centres

Variables:
Light: Colour, Correlated colour temperature, intensity, beam characteristics (angle, direction),
Human: Subjective perceived atmosphere, appreciation

The dynamic system:
Two ambiences were intended to be high arousal, pleasant ambiences, i.e. 'activating' and 'exciting', and two to be low arousal, pleasant ambiences, i.e. 'cosy' and 'relaxing'. (ibid., p. 862)

"Almost all lighting designers preferred to have no dynamics in the 'cosy' ambience. For the activating ambience most lighting designers preferred slow dynamics (i.e. with changes over minutes or hours) in the general lighting (so, for the illuminance and CCT). For the relaxing atmosphere, static lighting was preferred; only slow (with changes over minutes) dynamics were sug- gested in the intensity of the spotlights. Finally, for the exciting atmosphere most lighting designers preferred to have fast changes (i.e. in a time frame of seconds) in the intensity of the spotlights and in the colours of the accent lighting." (ibid., p. 863)

Concept:
Ambient Intelligent Lighting (AIL)

Published:
2013
Sekulovski, Dragan

Article:
Studies in ambient intelligent lighting

Field of science:
Human technology interaction

Objective:
Supporting everyday life activities, Technological exploitation (control and interaction)

"The goal of Ambient Intelligent environments is to support people in their everyday life activities through technology and media. By positioning the user and his needs in the center of attention and technology in a supporting role, Ambient Intelligence essentially adopts a user-centric design philosophy on Ubiquitous Computing." (3, p. 6).

Key terms:
Dynamic in nature
"The normal operating mode of most general use traditional light sources, disco lights being one of the few exceptions, is static and they only have an on/off functionality or a limited dimming range. This is contrary to lighting conditions in nature, which are inherently dynamic, from the slow change of the intensity and the color temperature of daylight during one day, to the fast flashes of lightning in a thunderstorm. Furthermore, most of the light effects we experience in nature are unpredictable on a certain timescale." (3, p. 68).

Stochastic dynamic
Similar to dynamic lighting scenes in nature, the resulting light effects are unpredictable, yet recognizable.

User centric effect driven lighting system
"Instead of the traditional system centric control driven approach to lighting design, Chapters 3, 4, and 5 present examples of user centric effect driven light design with increasing complexity." (ibid., p. 128)

Target group/ Context:
No specific target group, everyday environment, effect lighting

Variables:
Light: Colour, intensity, distribution, transition (smoothness),
Human: Preference, interaction (language), perception

The dynamic system:
"AIL systems have a model of the user and the context, and this can bring the interaction at a level that is closer to the concepts of the user. This enables the users to imagine their target experience of the lighting in the environment and communicate it to the system using a language that is natural to them. In this case, instead of controlling the switch, the user describes the desired effect the lighting system should have on the environment, which is then translated into controls for the system by a set of intelligent, context aware algorithms. This interaction paradigm is called effect driven." (ibid., p. 6).

"The set of intelligent context aware algorithms, embedded in distributed devices, providing a personalized and adaptive control of everyday devices is one of the central ideas of Ambient Intelligence. In the context of lighting systems, its application enables, through effect driven control, easier use of the advanced capabilities of the modern light sources.
uses psychophysical methods to explore and model the effects of interest. Finally, possible extensions to spatiotemporal models and interactive systems are discussed." (ibid.)

Concept:

Ambient Lighting Assistance (ALA)

Project: ALADIN (Ambient Lighting Assistance for an Ageing Population)

Coined and published:
2009

Article:
Ambient Lighting Assistance for an Ageing Population

Field of science:
social anthropology and information science, with particularly interested in interfaces and interaction between man and machines/computers

Objective:
to extend our knowledge about the impact of lighting on the wellbeing and comfort of older people and translate this into a cost-effective open solution. “The ”older elderly” with limited mobility, restricted access to daylight and a reduced social environment represent an important target group for ALA and other assistive systems.” (4, p. 15).

Key terms:
Biosignals
“The ALA software captures psychophysiological data supplied by a biosignal recorder via bluetooth connection, analyzing these biosignals (blood pressure, heart rate, respiration rate, skin conductance and muscle tension) with regard to the individual cognitive performance defined by the performance-resource function Alvarez et al., and controlling lighting devices (and blinds) according to the results of these analyzing routines. Feedback is given by smart biosensors, which are attached to the human body and operate with a 32-bit microprocessor including an analogue-to-digital converter for eight channels for input and a serial peripheral interface for output.” (4, p. 26).

Open and closed-loop systems
“An open loop system refers to a controller that does not use feedback to determine if its input has achieved the desired goal, a closed-loop system uses feedback on how the system is actually performing. This allows the controller to dynamically compensate for disturbances to the system. Finally, we ended up by defining a model which encompasses the interactions and interdependencies of the variables involved in salutogenesis and which illustrates the effectiveness of open and closed-loop systems.” (ibid., p. 13).

Salutogenesis
“The concept of salutogenesis which was developed by the American/Israeli sociologist Aaron Antonovsky (1979). According to this model, health cannot be understood as a state but has to be conceived as an ongoing process. Along with this idea goes the concept of a continuum between health and disease. A person’s state of health dynamically moves within this continuum. The process of moving on this continuum embraces several variables which have a substantial influence on the development of health, i.e. biological premises, psychological state and social embedding.” (ibid.).

Target group/ Context:
Older people, nursing homes or care facilities

Variables:

Light: intensity, light directions or colour

impetus: biosignals, individual needs and preferences, circadian rhythm

Human effect: psycho- physiological impact, subjective perceptions and performance, needs, personalized to their requirements, anticipatory of their behaviour and responsive to their presence.

The dynamic system:
ALA adapts itself continuously in accordance with an individual’s biosignals and specific situations.

“a combination of innovative technological solutions from lighting technology, smart sensor technology and computer- and information technologies ambient lighting' with varying temperature and brightness has been in use for some time. However, the user has no possibility to interact with the predefined control strategy (mostly defined by the time of the day) and the lighting solutions do not take into account individual differences. capturing and analysing the individual and situational differences of the psycho-physiological effects of lighting, and enabling the users to make adaptations tailored to their specific needs and wishes. user-specific nor are they able to react to different affective states of users or situations, An intelligent open-loop control and biofeedback system which can adapt various light parameters such as intensity, light directions or colour in response to the psycho- physiological data, which are continuously registered by the system.” (ibid., p. 6).

“Overall the strategy to use „normal” products in an innovative way proved to be very adequate in terms of functionality. Future efforts to improve the system or even to make it ready for serial production can concentrate on the core functions like optimising the software, designing a less intrusive and more reliable sensor, and producing more cost-efficient lighting devices. Besides, it should be possible to make ALADIN compatible with any existing TV.
The findings from the field tests show that frequency and duration of using automatic light adaption have some statistically significant positive correlation with indicators for wellbeing.” (ibid., p. 7).

Concept:
Biologically Active Lighting (BAL)

Published:
1986

Article:
Effect of biologically active light and partial sleep deprivation on sleep, awakening and circadian rhythms in normal

Field of science / Key theory:
Psychology

Objective:
"A chronobiological method whereby one tries to change the psychopathology of patients by altering their activity- rest (light-dark) cycles." (5, p. 86)".
"(BAL) uses artificial light to expand daylight to constant length the year round, one may assume that the human environment is without seasonal time cues and that social influences may be of more importance." (ibid., p. 83).

Key terms:
Drug evaluation
Biologically Active Lighting considers the encephalotropic and psychotropic properties in a systematic way. Similar to the early clinical drug evaluation studies with potentially antidepressant substances, BAL's properties are investigated like a drug. (ibid.)

Target group/ Context:
Inhabitants of polar regions

Variables:
Light: intensity
Human: circadian rhythm, depression,
Human effect: objective (melatonin, cortisol, circadian system, sleep, depression, circadian body temperature) subjective (sleep wellbeing)

The dynamic system
"Thus, it was of considerable interest that Lewy et al. [1980] could demonstrate that human melatonin secretion can be suppressed by sunlight and bright artificial light but not by light of ordinary indoor intensity. These findings raised the possibility that human circadian and seasonal rhythms can be regulated by bright artificial light substituted for sunlight. Indeed, Lewy et al. [1982] could show that a manic-depressive patient with a winter depression improved when several winter days were extended with bright artificial light." (ibid.).

"Exposure to bright light was from 5.00 to 9.00 p.m. and from 6.00 to 9.00 a.m. 36 Tungsram daylight 55 fluorescent tubes with 40 W each gave a light with 4,500 Ix intensity at ceiling lev- el, 2,800 Ix at eye level while sitting and I, 700 Ix a floor level." (ibid.).

Published:
1993

Article:
The effect of biologically-active light on the noo- and thymopsyche and on psychophysiological variables in healthy volunteers

Field of science:
Psychology

Objective:
Why bright light is effective in SAD patients or in shift workers or jet-lag conditions is unclear. The feeling of being alert and full of energy might be an effect on the biological clock. Bright light works as a ‘Zeitgeber’ on the sleep-wake cycle and the wake-activity cycle by synchronizing internal cycles and amplifying the internal rhythms.

Key terms:
Nootropic effect
Also known as smart drugs and cognitive enhancers, are drugs, supplements, and other substances that improve cognitive function, particularly executive functions, memory, creativity, or motivation, in healthy individuals.

Zeitgeber
Zeitgeber (Bright white light) effects the sleep-wake cycle and the wake-activity cycle by synchronizing internal cycles and amplifying the internal rhythms.

Target group/ Context:
SAD patients, no context mentioned

Variables:
Light: intensity duration
Impetus: circadian rhythm
Human: intellectual mnestic performance, alertness, mood and psychophysiological variables, subjective wellbeing

The dynamic system:
“Between 9 a.m. and 5 p.m. the subjects underwent intermittent light exposure (interrupted by psychometric and psychophysiological investigations) lasting for 4 h (see time schedule as shown in Fig. 1). The exposures were carried out 30 min before the end of the 1st and 2nd hour, respectively, as well as 1 hour before the end of the 4th, 6th and 8th hour after baseline investigations. On one day, biologically-active light with an intensity of 2500 lux (36 Tungsram Daylight 55 Fluorescent tubes).” (6, p. 28).

Concept:
Candlelight-style OLED (CSO)

Coined and published:
2014

Article:
Candlelight style organic light-emitting diode: a plausibly human-friendly safe night light

Field of science:
Photonic

Objective:
Candles emit sensationally warm light with a very low color temperature, compara- tively most suitable for use at night. In response to the need for such a human-friendly night light, we demonstrate the employment of a high number of candlelight complementary organic emitters to generate and mimic candlelight based on organic light emitting diode (OLED)." (7, p. 1).

Key terms:
Human friendly light/physiologically friendly light
"Researchers have rarely focused on developing physiologically friendly light sources, especially for use at night. Color temperature (CT) of light plays an important role in human physiology and psychology.7–14 Numerous studies have shown that high CT-lighting source and intensive white light or light with strong- blue emission drastically suppresses the secretion of melatonin (MLT), an oncostatic hormone. Importantly, the lack of MLT due to frequent exposure to intense light at night can increase the risk of breast, colorectal, and prostate cancers.10 Suppression ofMLT secretion has been reported upon exposure of 3000- or 5000-K fluorescent lights at 200 lx,15 which is dimmer than the typical 500-lx office lighting, but brighter than the 100-lx lighting used at home.10,15 Much milder suppression can only be observed as the CT is further reduced." (ibid.).

Target group/ Context:
No specific target group. Nocturnal lighting/ Light At Night (LAN)

Variables:

Light:	CT, CRI, efficacy
Human effects:	Nocturnal melatonin suppression
Impetus:	special occasions

The dynamic system:
"The resulting emissive spectrum shows an 80% similarity with that of the candle. The candlelight style OLED exhibits a 19-lm⁄Wefficacy and a 93 color rendering index (CRI) while the efficacy is 0.1 lm⁄Wand CRI 83 for candles. Furthermore, candlelight has a CT varying with the variation in emissive flame position, as seen in Fig. 1. The color temperature ranges from 1847 to 2626 K, with a 1914 K at the brightest spot." (ibid., p. 2).
"The importance of light sources with a low CT can be further realized by the fact that candle-light, which exhibits a CT around 1900 K is capable of creating romantic atmosphere during dinner time.16 The pleasant sensation may originate from the naturally occurring MLT secretion, which helps people relax. In cases where lighting is needed, this secretion is less suppressed." (ibid., p. 1).

Concept:
Circadian Lighting (CL)

Published:
2010

Article:
Circadian light

Field of science:
Photobiology

Objective:
Light is formally defined as optical radiation capable of providing visual sensation in humans. The current definition of light does not directly relate to its effects on the human circadian system

Key terms:
Circadian light (CLA) and circadian stimulus (CS) calculation
"[…] it is increasingly important that a measurement system, such as CL, CLA, and CS as presented here, be developed for quantifying the photic stimulus for the human circadian system." (8, p. 9).

Target group/ Context:
No specific target group

Variables:

Light:	spectral power distributions
Impetus:	circadian biological rhythm
Human:	nocturnal melatonin suppression

The dynamic system
"The definition of circadian light proposed here is based on the current knowledge of the neuroanatomy and neurophysiology of the human retina and on published psychophysical studies of nocturnal melatonin suppression using lights of different spectral power distributions." (8, p. 1).
"Light is formally defined as optical radiation capable of providing visual sensation in humans. The current definition of light does not directly relate to its effects on the human circadian system. Since temporal patterns of retinal light (and dark) exposures regulate the human circadian system and since disruption of the circadian system has broad implications for health and well-being [2-9,52,53], it is becoming increasingly important to develop a new definition of circadian light." (ibid., p. 2).
"Toward that end, the present paper has placed the evolving development of a definition of circadian light into the historical context of light as it has been defined for metrology and as it affects human vision. As described here, an additive "photodian" luminous efficiency function for circadian light will probably never be exactly comparable to the photopic luminous efficiency function used in conventional photometry based upon the human visual system. Nevertheless, it is increasingly important that a measurement system, such as CL, CLA, and CS as presented here, be developed for quantifying the photic stimulus for the human circadian system." (ibid., p. 9).

Published:
2017

Article:

Delirium and effect of circadian light in the intensive care unit: A retrospective cohort study

Field of science:
Medicine, health studies

Objective:
"The role of circadian light for this condition is unclear. association between delirium and circadian light for patients in the ICU. A significant part of patients at ICUs suffer from episodes of delirium, and these patients have demonstrated worse long-term cognitive and physical impairments, disturbed sleep-wake cycles, sleep architecture, and circadian rhythms." (26)

Key terms:
Circadian light and delirium
"Patients with delirium in the ICU have disturbed sleep-wake cycles, sleep architecture, and circadian rhythms. The circadian rhythm is controlled from the suprachiasmatic nucleus (SCN) in the hypothalamus. When blue light with a wavelength of 460–480 nm reaches the photoreceptors in the retina, the melatonin secretion from the pineal gland is suppressed by signals from the SCN. Blue light of this wave- length is mainly present in the morning. In the absence of blue light, melatonin secretion pro- motes sleep." (ibid., p. 2).

Target group/ Context:
Patients in intensive care units (ICUs) suffering from delirium.

Variables:

Light: Intensity, time
Human: Delirium: Delirium was defined as at least one positive CAM-ICU score or treatment with haloperidol.

The dynamic system:
"In the hospital, artificial light is turned on around-the-clock. This results in constant exposure to blue light and melatonin suppression. This may disturb the natural sleep- wake cycle and makes patients more vulnerable to developing delirium
At the ICU, all rooms had windows and access to natural light. Three out of nine beds had a supplemental circadian light system (Luminex, Horsens, Denmark). The amount of blue light (460– 480 nm) was strongest between 07:00 hours and noon. At this time, the light intensity was at maximum strength. From noon until 20:00 hours, the light turned to a warmer tone still with some blue light components. From 20:00 hours to 23:00 hours, the light turned a warm orange. From 23:00 hours, the light was completely free of blue tones. In rooms without circadian light, the artificial light followed the normal daily rhythm in the unit." (ibid).
"In the circadian light room, the light intensity rose at 06:00 hours. At 19:00 hours, the intensity went down and a minimum was reached at 20:30 hours (50 lux) (Fig. 1). In the conventional room, the light intensity rose later in the morning and intensity was lower throughout the day and night. (ibid., p. 3).

Concept:
Circadian Healthy Light (CHL)

Published:
2014

Article:
Protecting the Melatonin Rhythm through Circadian Healthy Light Exposure

Field of science:
Biology

Objective:
Circadian entrainment.
"The cycle of sunrise and sunset has provided a reliable time cue for many thousands of years, until recently when modern life and the "24-hour society" intensified exposure to artificial lighting environments, both during the day and at night, as people engage in shift work and leisure time is displaced towards the nighttime hours. Thus, it is important to find a way to illuminate the night that permits the circadian entrainment and respects the melatonin rhythm. Reducing the blue component of nocturnal light could prevent light-induced disruption of the circadian system and provide an attractive means of reducing the health risks induced by LAN. […] Knowledge of retinal photoreceptors and the discovery of melanopsin in some ganglion cells demonstrate that light intensity, timing and spectrum must be considered to keep the biological clock properly entrained." (10, p. 23452).

Key terms:
Light at night (LAN)
"Nights are excessively illuminated (light at night), whereas daytime is mainly spent indoors, and thus people are exposed to much lower light intensities than under natural conditions. In spite of the positive impact of artificial light, we pay a price for the easy access to light during the night: disorganization of our circadian system or chronodisruption." (10, p. 23448).

Chronodisrupting (CD)
"Epidemiological studies show that CD is associated with an increased incidence of diabetes, obesity, heart disease, cognitive and affective impairment, premature aging and some types of cancer. Knowledge of retinal photoreceptors and the discovery of melanopsin in some ganglion cells demonstrate that light intensity, timing and spectrum must be considered to keep the biological clock properly entrained." (ibid., p. 23453).

Target group/ Context:
No specific target group (suggested shift workers, social jetlag, elderly, Inhabitants of high altitudes).

Variables:

Light:	Intensity, timing, spectral properties
Impetus:	biological circadian rhythm
Human effect:	Sleep, melatonin, cortisol, circadian system

The dynamic system:
- In order to maintain the health of our circadian system, appropriate lighting levels during the day should be recommended.
- Diurnal lighting should not be poor in wavelengths in the 460–480 nm range, since maximum human circadian spectral sensitivity occurs in this part of the spectrum.
- Darkness during the night is desirable, and when illumination is a must, the abovementioned specifically active wavelengths should be avoided, shifting to a more reddish spectrum. Interestingly, bluish wavelengths are the ones that most interfere with astronomical observations, and "whiter" light is likely to increase the potential range of environmental impacts on other living organisms. Thus, reducing light pollution would have positive effects, not only on human health, but also in terms of cultural and environmental aspects.

- Since our recently acquired lifestyle habits seem to require illumination at night, new lighting technologies using the favorable spectrum and intensity should be developed to preserve circadian system functioning both at night and during the day inside buildings.
- Importantly, not all wavelengths of light are equally chronodisrupting. Blue light, which is particularly beneficial during the daytime, seems to be more disruptive at night, and induces the strongest melatonin inhibition. Nocturnal blue light exposure is currently increasing, due to the proliferation of energy-efficient lighting (LEDs) and electronic devices. Thus, the development of lighting systems that preserve the melatonin rhythm could reduce the health risks induced by chronodisruption.

Concept:
Cycled Lighting (CyL)

Published:
2000

Article:
The effect of cycled light versus continuous near darkness on growth and development of preterm infants born at less than 31 weeks gestation

Field of science:
Medicin, health studies

Objective:
Cycled light is expected to promote the development of circadian rhythms, sleep-wake states, physical growth and neurodevelopment in neonates, but it was unclear at what time cycled light is appropriate for the most immature preterms.

“The environment of the neonatal intensive care unit (NICU) is unlike the environment of either the fetus or healthy fullterm infant (Eckerman, Oehler, Medvin, & Hannan, 1994; Gottfried, 1985; Holditch-Davis, 1990b). The fetus develops in an environment rich with auditory, tactile, and kinesthetic sensory stimuli, circadian stimulation, and near darkness, whereas the term infant develops in a cycled light environment with emerging circadian influences and multiple sensory stimuli (McMillen, Kok, Adamson, Deayton, & Nowak, 1991; Rivkees, 1997). The NICU environment is different from both of these environments. Thus, the needs of preterm infants can not be extrapolated from what is known to be best for fetuses or healthy fullterms. Unlike the fetus or fullterm infant, preterm infants must use immature organ systems (including the auditory and visual system) to deal with the environment in which they exist (Gottfried, 1985). For example, preterm infants exhibit sleep-wake patterns that are not typical of either fetuses or fullterm infants (Holditch-Davis, 1990a).“ (11, p. 9).

Key terms:
Ultradian rhythm
Ultradian rhythm refers to cycles with a period shorter than a day but longer than an hour (The Oxford English Dictionary).

Intrauterine environment
“The uterus provides a rich, appropriate environment for sensory development and, thus, the extrauterine environment may not be appropriate for the preterm infant. An important part of the intrauterine experience may be its rich, but modulated, sensory experience. However, stimuli in the uterus do not typically include visual stimuli, and the uterus usually lacks the concomitant physiological stress that preterm infants must endure in the neonatal intensive care nursery environment.” (ibid., p. p.18).

Target group/ Context:
Preterm infants, NICU

Variables:
Light: Time, intensity
Human: heart rate, growth, length of hospitalization

The dynamic system
Near darkness was defined as lux levels between 5 and 10 at level of the infant’s eye. Light was defined as lux levels between 200 and 225 at the level of the infant’s eye. Cycled light was defined as 11 hours of continuous darkness followed by a transition hour and 11 hours of continuous light then another transition hour before starting over. Thirty-two

Attempts to modify nursery light levels for preterm infants have focused on providing continuous near darkness to mimic the intrauterine environment (Als et al., 1986). However, it is impossible to replicate the womb for preterm infants because the fetus develops in a uterus with both circadian rhythm influences and near darkness (Blackburn, 1998). Cycling between day and night lighting promotes circadian rhythms (Rivkees, 1997).

Concept:
Dawn simulated light (DSL)

Published:
2015

Article:
Dawn simulation vs. bright light in seasonal affective disorder: Treatment effects and subjective preference

Field of science:
Psychiatry

Objective:
"[…] treatment of seasonal affective disorder." (12, p. 87).

Target group/ Context:
SAD patients, bed room in private homes

Variables
Light: intensity, time, duration, distance to eye
Human: SAD symptoms subjective, preference

The dynamic system
"Dawn simulation (Lumies dawn simulator) was a gradually increasing incandescent light during the last 30 min of sleep achieving 100 lx at the distance of 50 cm from the pillow at the alarm beep, and subjects were asked to place the dawn simulator closer to their open eyes (30 cm: 250 lx) for a further 15 min for "an extra energy charge" (Terman and MacMahan, 2013)." (ibid., p. 88)

"Bright white light for SAD was first described in 1984 (Rosenthal et al., 1984) and conventionally utilizes a fluorescent light box for 30 min daily, usually in the morning. Dawn simulation is an alternative, time-saving light therapy, first described in 1989 (Terman et al., 1989). Both types of therapy were recognized by American Psychiatric Association as the first-line treatment for winter depression (Golden et al., 2005)." (ibid.)

Coined:
2003

Article:
The effect of dawn simulation on the cortisol response to awakening in healthy participants

Field of science:
Psychiatry

Objective:
"In healthy individuals cortisol secretory activity shows a marked diurnal rhythmicity characterised by peak levels following awakening and a declining pattern thereafter (Edwards et al., 2001a)" (13, p. 925).

Target group/ Context:
No specific target group, bedroom

Variables:

Light: Intensity, time, duration

Human: cortisol response to awakening, subjective mood, subjective arousal

The dynamic system:

"'Natural Alarm Clock' (Outside In, Cambridge Ltd), a low intensity bedside light that gradually increases in luminescence to approximately 250 lux over 30 mins before awakening when an audible alarm sounds." (ibid., p. 926).

"Greater arousal measured by the stress-arousal checklist (Mackay et al., 1978) in the dawn simulation condition. Participants reported that they felt more alert and less tired when using the dawn simulator to wake them in the morning rather than their usual alarm clock." (ibid., p. 929).

Published:

2013

Article:

Effects of Artificial Dawn and Morning Blue Light on Daytime Cognitive Performance, Well-being, Cortisol and Melatonin Levels

Field of science:

Psychiatry

Objective:

"Artificial dawn as a countermeasure for impaired cognitive performance and mood under sleep restriction." (14, p. 988)

Target group/ Context:

No specific target group, bedroom

Variables:

Light: Intensity, Correlated colour temperature, time, duration

Human: cortisol and melatonin response, subjective mood, objective cognitive performance, subjective wellbeing, subjective sleepiness

The dynamic system:

Polychromatic light gradually increasing from 0 to 250 lux during 30min before wake-up time; the light remained around 250 lux for 20min after wake-up time. Placed near the bed at eye level. The illuminance, photon density, correlated color temperature and melanopic illuminance of the dawn simulation light, measured 45cm from the device were as follows:

- 5min after light onset: 1.2 lux, 1.9E?16/m2 s, 1090 K, 0.2 m-lux
- 15min after light onset: 13 lux, 1.4E?17/m2 s, 1500 K, 7.5 m-lux
- 24min after light onset: 78 lux, 7.1E?17/m2 s, 2200 K, 120 m-lux
- 30min after light onset: 250 lux, 2.4E?18/m2 s, 2750 K, 620 m-lux (ibid., p. 990)

Concept:
Drug Light (DrL)

Published:
2009

Article:
Light Hygiene: Time to make preventive use of insights – old and new – into the nexus of the drug light, melatonin, clocks, chronodisruption and public health

Field of science:
Medical science

Objective:
- Improve public health and prevent disease
- Considering light as a possible new drug, treatment or therapy
- A cheaper and ameliorative drug

"With almost any other drug, there can be severe ''side effects" of light exposures. Indeed, if we ignore principles of light hygiene, such as the appropriate timing and dosing of light, this can lead to chronodisruption, ''a critical loss of time order, i.e., a disorder or chaos of an otherwise physiological timing at different organizational levels, including the gene expression levels in individual cells" [3]. Importantly, as a relevant disturbance of the temporal organization or order of physiology, endocrinology, metabolism and behaviour, chronodisruption can possibly lead to severe chronic processes, including premature ageing and cancers Importantly, such awareness should lead to require – as is true for any potent drug – the realization that dose and timing should be understood and regulations as to its proper use developed and followed appropriately. This could be a means to two ends: to al- low light's benefits on the one hand and to disallow its adverse side effects, including those that lie on chains of causation which may lead to cancer and premature ageing, on the other." (15, p. 538).

Key terms:
Zeitgeber and Light Hygiene
"[…] appropriate balance of exposures to the key Zeitgeber light in terms of ''light hygiene", implying strong and appropriate rather than weak and confusing temporal information. This focus on ''light hygiene", and thus on the key Zeitgeber light, does not mean to ignore that there are multiple entrainment pathways for our circadian clocks. Indeed, when dealing with light, chronodisruption and a multitude of adverse health effects, we ultimately need to consider Zeitgeber cues, and their possible interplay, beyond light alone. Confusions since light possesses a rather unique and exclusive Zeitgeber role and in view of its ubiquitous nature, a specific, preventative focus on ''light hygiene", as a contribution to a general ''Zeitgeber hygiene", is warranted." (ibid., p. 540).

"Light showers"
"''Light showers", for instance during a walk outdoors at specific times of the day." (ibid.).

Target group/ Context:
No specific target group, no specific context

Variables:

Light:	Time, spectral distribution, intensity,
Impetus:	24 hour biological circadian rhythm
Human:	Preventing diseases, no side effects of wrongly used lighting Sleep, depression, cancer, premature ageing, melatonin

The dynamic system:
"In conclusion, the public should be informed and know that there are critical issues involving the drug light theme. Scientists should determine what quality and quantity of light and what timing of the latter ''makes the poison" on the one hand and what can be considered beneficial, on the other." (ibid.)

“Timing, quality (wavelength), quantity (dose) and side effects, including chronodisruption, of light exposures can be critically important for health and disease in man. In terms of cause-and-effect relationships, we work here with the term exposure, rather than substance, when talking about drug or drug equivalent. With this very labelling could bring about the necessary awareness for both its beneficial working but also for its possible detrimental side effects.” (ibid., p. 537).

“Indeed, we know that the circadian system of many, if not the majority of individuals, benefits from unequivocal, strong time, i.e., light, cues. Recall that many of us work in offices with 500–1000 lux exposures while during Summer and in Winter days we can experience as much as 100,000 and 20,000 lux intensities outdoors, respectively. Other considerations include the development of light sources that are devoid of the critical wavelengths of light (458–484 nm) that alter circadian rhythms and lead to melatonin suppression. Alternatively, goggles or lenses which filter these critical wavelengths may be of value [4,5]. Overall, though, that blocking light exposures alone would decrease cancer occurrence caused by chronodisruption is an unlikely expectation in our view.” (ibid., p. 540).

Concept:

Dynamic Lighting (DL)

Published:
2010

Article:
Effects of dynamic lighting on office workers: First results of a field study with monthly alternating settings

Field of science:
Human technology interaction

Objective:
Well-being and performance, supporting modern lifestyle (social jetlag)
"Dynamic lighting is an innovative lighting solution that aims to harness these potential effects of lighting characteristics such as colour temperature and illuminance explore lighting as a potential environmental feature impacting office workers' well-being." (16, p. 345).

Key terms:
Co-variables/intervening variables,
Other variables potentially impacting the effects of light are under the experimenters' control in contrast to the situation in real-world research.

Target group/ Context:
No specific target group, tested in office environment

Variables:

Light: Intensity, correlated colour temperature, time
Impetus: Diurnal work rhythm, biological circadian rhythm
Human: Recovery from mental strain, subjective alertness, subjective sleep, subjective performance, appreciation of lighting

Need to recuperate from attention fatigue and stress), vitality, alertness, headache and eyestrain, mental health, sleep quality and subjective performance, subjective evaluations of lighting conditions

impact on biological and psychological processes, different patterns for the physiological measures and the psychological measures: Effects of lighting on physiological measures were time dependent whereas effects of lighting on psychological measures were independent of time of day. the need for recovery (i.e. the need to recuperate from attention fatigue and stress), vitality, alertness, headache and eyestrain, mental health, sleep quality and subjective performance. Subjective evaluations of lighting conditions

The dynamic system
"Dynamic lighting, colour temperature and illuminance vary during the day according to a preset protocol, aiming to support or even enhance the natural rhythm of employees' alertness. A potential protocol, also applied in the present study, is presented in Figure 1. This particular protocol does not exactly emulate the natural pattern of daylight, but instead offers a higher illuminance and colour temperature in the morning and after lunch- time with lower and warmer white light during the late morning and afternoon.

Including natural light
"In the dynamic lighting condition, employees experienced a gradually changing lighting scenario (500–700 lx; 3000–4700K) with a higher light level and colour temperature in the morning and after lunchtime (Figure 1). The static condition provided an illuminance of 500 lx at a colour temperature of 3000 K." (ibid., p. 350).

"Research has shown that the level of cortisol increases when exposed to high light levels in the morning, but not in the afternoon1 or evening.2 These biological effects are dependent on the colour temper- ature, light level, duration and timing of exposure as well as on the size and position of the light source." (ibid., p. 346).

Published:
2012

Article:
Assessment of a New Dynamic Light Regimen in a Nuclear Power Control Room Without Windows on Quickly Rotating Shiftworkers—Effects on Health, Wakefulness, and Circadian Alignment: A Pilot Study

Field of science:
Neurology

Objective:
Circadian alignment
"It was further hypothesized that during the morning shift dynamic light would decrease melatonin levels and improve sleepiness and sleep because of a more rapid circadian alignment to morning shifts." (17, p. 642).

Key terms:
Circadian alignment
"During the morning shift dynamic light would decrease melatonin levels and improve sleepiness and sleep because of a more rapid circadian alignment to morning shifts." (17, p. 641).

Target group/ Context:
Night shift workers, Workplaces without windows and in the dark season of the year

Variables:

Light:	Correlated colour temperature, intensity, time,
Impetus:	Diurnal work rhythm, biological circadian rhythm
Human:	Alertness, sleep, and adaptation to rotating shiftwork

The dynamic system:
"A dynamic light design, […], with varying spectral content and light intensity to help circadian adaptation of shiftworkers showed promising alerting effects at night and facilitated quick return to day-orientation for sleep and wake functions. The study is in line with regulatory offices overseeing the nuclear industry that have highlighted the need to improve wakefulness and safety in the control room;" (ibid., p. 648).

Deprived from daylight.

"The study demonstrates that artificial lights at work could dominate the total daily light exposure of shiftworkers, especially for those who are employed in workplaces without windows and in the dark season of the year, demonstrating its major influence on circadian phase changes, possible long-term health, and safety at work." (ibid.).

Concept:

Dynamic Lighting System (DLS)

Published:
2015

Article:
Dynamic lighting systems in psychogeriatric care facilities in the Netherlands: A quantitative and qualitative analysis of stakeholders' responses and applied technology.

Field of science:
Building science

Objective:
Wellbeing, mental health,
"Long-term care facilities are currently installing dynamic lighting systems with the aim to improve the well-being and behaviour of residents with dementia. […] The main reason for purchasing dynamic lighting systems lied in the assumption that the well-being and day/night rhythmicity of residents could be improved." (18, p. 617).

Key terms:
Dynamic bright light solutions
"The underlying assumption of such systems [dynamic bright light solution red.] is that human beings evolved in daylight conditions, and that the dynamic component in the emission of light contributes to the positive effects of the ambient bright light systems (Figure 1). In addition, the required illuminance levels are much higher than average, i.e. values of two to five times higher than normal indoor conditions in group living rooms of care facilities. In addition, so is the (correlated) colour temperature of the light, which should exceed 5000K. This is much higher than the normal values that lie between 2700K and 4000K. In practice, both illuminance and colour temperature are controlled through dedicated software. Generally, only the main luminaire in the living room is steered via a dynamic protocol. In practice, the lighting follows a protocol with instead of one, two peak moments. The reason is that the time schedule of people living in a care facility normally exists of a rest period after lunch time." (ibid., p. 618).

Target group/ Context:
Dementia patients
Care facilities

Variables:

Light:	Level, correlated colour temperature
Impetus:	Circadian biological rhythm
Human:	well-being and rhythmicity of residents can be improved

The dynamic system:
"All systems were equipped with several tubular fluorescent light sources with two different Tcp values, namely 2700K and 6500 K. By mixing light sources within the luminaire, a colour temperature between 2700K and 6500K can be achieved. In the living rooms of facilities A, B and D, all lighting scenarios were programmed to start in the morning at a low E and a low and warm Tcp. Until 09:00 h, these values gradually increased to the maximum values. After lunchtime, the values were again set to a low E and Tcp for about 1 h, with a final boost of high E and Tcp until the end of the afternoon. At the end of the afternoon/beginning of the evening, the values gradually decreased towards the lower values again. In living room C, no dynamic light scenario was implemented. Instead, a continuous high light level and Tcp were provided by the DLSs." (ibid., p. 621-622).

Concept:

Enriching Lighting Design (ELD)

Published:
2009
Elizabeth C. Brawley

Article:
Enriching lighting design

Field of science:
Neurology

Objective:
Enable visually impaired
"Lighting is a powerful design tool that can be used to support individuals of any age to engage in the normal activities of their daily lives. Higher quality and increased quantities of appropriate lighting help to maximize abilities and minimize challenges for many individuals with compromised vision. The challenge becomes adapting the environment to support the needs of the users and to help compensate for vision changes, no matter" (19, p. 189).
the cause.

Key terms:
Good lighting
"Good lighting design today comprises energy efficient, indirect electric lighting and light controls, combined with greater use of large skylights and larger windows for daylighting. Research has confirmed that light not only enhances vision but contributes to overall good health. Increased access to safe, healthy outdoor environments can encourage residents and patients outdoors into the sunlight for healthy bright light exposure to reset circadian cycles, for bone health, exercise and to provide a general sense of in- creased well-being. These minimally invasive interventions may prove to be one of the most affordable prescriptions for fewer fractures, better sleep quality, reduced depression and an increased sense of wellbeing." (ibid., p. 198).

Target group/ Context:
Visually impaired, hospital rehabilitation settings.

Variables

Light:	Daylight, glare, illumination level, reflectance, CRI,
Impetus:	Biological circadian rhythm, daily life rhythm
Human:	

The dynamic system:
Artificial lighting
"According to study by AncoliIsrael and Kripke [1], published in the Bulletin of Clinical Neurosciences, many older adults, particularly those living in institutional settings, don't receive adequate exposure to bright light needed for the synchronization of their circadian system. This is most likely due to the fact that the best source of bright light necessary for synchronization of the circadian system is daylight. Typical interior lighting does not contain the spectrum to which the circadian system is most sensitive." (ibid., p. 195).

Daylight
"Bright light in the morning, reduced electric light at night and eliminate light when one is sleeping. The best and most affordable source of the bright light necessary for synchronization or entrainment of the circadian system is daylight. Daylight also stimulates the production of serotonin, one of the body's "feel good" chemicals and one of the most pleasant side effects is its ability to cheer people up and feel alert. It's like a miracle drug from the sun." (ibid., p. 196).
"Increasing available light during the day within adaptive healthcare environments can be accomplished by employing greater use of skylights and daylight principles. Natural light use can be maximized in conjunction with electric lighting through the use of light-sensitive controls." (ibid., p. 195).

Overall

This concept are vaguely defined, and are superficially touching upon the various light qualities – not for lighting researchers but for health environment designers. Brawley argues that electrical light can't act as an entrainment factor for the circadian system. This concept is prioritizing daylight as the main light source, and good electrical lighting for visual orientation – also restriction in order not to disturb (elderly and very fragile) circadian system.

Concept:
Healthy Lighting

Published:
2005
Myriam Aries

Article:
Human lighting demands: healthy lighting in an office environment

Field of science:
Human-Technology Interaction

Objective:
Wellbeing, Supporting modern life style, psychological and physiological health,
"The objectives of this research were to characterize lighting conditions in current office types with regard to current standards and non-visual variables and to develop (conditions for) lighting concepts and system solutions that meet both visual and non-visual demands of humans."(20, p. 7).

Target group/ Context:
No specific target group, working environment

Variables
Light: Intensity, distribution, inter-architectural parameters
Impetus: Daylight, activity
Human: Objective performance (as both visual and non-visual effect), fatigue, subjective alertness, subjective sleep, subjective mood, perception, appreciation, subjective glare, visual interest

The dynamic system:
"With regard to non-visual performance, light intensities on the vertical plane of 1000- 1500lux are required according to literature and standards. These high light levels are not demanded all day and a dynamic light dosage is therefore recommended. The current recommendations for maximum luminances are based on work with VDT's. With increasing lighting levels in the room, not only the visibility at the computer monitor might be critical, also the visual comfort limits of human beings could be reached." (ibid., p. 94).

"Present-day offices are it by a combination of daylight and electric lighting. Daylight entering through a vertical window has a very strong vertical illumination component, as opposed to a ceiling-based electric down-lighting system, with mainly a horizontal illumination component. Designs for a daylight opening, façade and/or office room based on visual criteria for sufficient light on the horizontal working plane do not (automatically) meet criteria for healthy office lighting. The amount of light entering the human eye is not directly and related proportionally to the horizontal illuminance on the working plane. Therefore, when designing healthy office lighting, both the horizontal illuminance and the vertical (or retinal) illuminance should be used as design parameters." (ibid., p. 101).

Daylight
"No building can be lit by daylight alone because daylight is not 'reliable' according to the weather, the time of day or the time of year. Generally, it does not even reach all areas in a building and sometimes the intensity is too low. Higher demands for task lighting lead to the use of the combination of daylight and electric lighting." (ibid., p. 7)

Concept:
Human-Centric-Lighting

Published:
2016
Peter Boyce

Article:
Editorial: Exploring human-centric lighting

Field of science:
Not specified, mixed fields (physics, photobiology)

Objective:
Wellbeing, energy efficiency, supporting modern lifestyle, cognitive performance, circadian entrainment, mental and psychological health,
"What the people who talk about human-centric lighting mean is lighting that considers both the visual and non-visual effects of exposing humans to light and that widens the range of possible effects from visual performance and comfort to sleep quality, alertness, mood and behaviour with consequences for human health, learning and spending." (35).

Target group/ Context:
No specific target group, no specific context

Variables:
Light: Intensity, correlated colour temperature, time, duration
Impetus: Circadian biological rhythm,
Human: Circadian system (objective non-visual effects), alertness, sleep, wellbeing, behaviour (subjective non-visual effects), visual acuity (objective visual effect)

The dynamic system:
Dynamic lighting design not specified.
"In many ways, human-centric lighting is new land waiting to be explored. As with any exploration, it would be unwise to rush out into the wilderness without careful preparation. Preparation requires knowledge and this can only be gained by careful research into the importance, magnitude and reliability of the effects. It is only in this way that successful exploration can be ensured." (ibid.).

Published:
2016

Article:
IALD White paper: Lighting Design for Health, Wellbeing and Quality of Light, A Holistic Approach on Human Centric Lighting

Field of science:
Electrical engineering, lighting design

Objective:
Circadian entrainment
"Human Centric Lighting is the concept describing the connection between lighting, health and wellbeing. Lighting that focuses on people should balance visual, emotional, and biological benefits of lighting and promote good vision while satisfying the emotional and biological needs of the users. The latest development and work done in the field in the last 15 years found that lighting, especially Human Centric Lighting, also stimulates non- visual effects on human psychology and physiology." (22, p. 1).

Key terms:
Photo Biological / "Blue Light Hazard"
"The interaction of blue light with molecules constituting the retina or accumulating in the retina with age or in pathological conditions can induce damage to RPE 2 cells, photoreceptor cells, and to ganglion cells. The so called "blue light hazard" was identified […] The potential phototoxic retinal damage is expected to occur with wavelengths in the blue light spectrum between 400 and 460 nm (excitation peak at 440 nm)" (ibid., p. 5).

Target group/ Context:
No specific target group, No specific context

Variables:

Light:	Intensity, correlated colour temperature, timing, duration,
Impetus:	Circadian biological rhythm
Human:	Performance, alertness, sleep,

The dynamic system:
"Lighting Europe is defining Human Centric Lighting through basic notions that seem self-evident but most of the time are being ignored. They have stressed the difference between artificial lighting being static whereas natural light is dynamic. In the last four to five years, companies have introduced tunable white luminaires to try and simulate the dynamic nature of daylight and the technology is becoming increasingly more affordable. However, both in the control methodology and the actual determination of the appropriate protocol or schedule, we still have a lot to learn and lighting designers should be very responsible in their use." (ibid., p. 8).

"In order to activate the circadian system, greater amount of "polychromatic" white light is required. The circadian system is more sensitive to short wavelength blue light while the visual system is most sensitive to the middle portion of the visible spectrum. The most important aspect is that although our visual system is not significantly dependent on the timing of light exposure, therefore responding well to light stimulus at any time of day and night, the circadian system can respond with a phase advance or delay, interfering with the synchronization of our biological clock and a normal day / night cycle." (ibid., p. 2).

Concept:
Light-Dark Cycle (LDC)

Published:
2004

Article:
Short-term effects of a disturbed light-dark cycle and environmental enrichment on aggression and stress-related parameters in male mice

Field of science:
Medical science (laboratory animals)

Objective:
The health and well-being of animals, in particular of laboratory animals

Key terms:
Disturbed lighting – semi-natural lighting
Irregular lighting periods relative to the natural 12:12 hours natural light-dark rhythm – as opposed to semi-natural light-dark cycle.

Target group/ Context:
Laboratory animals, laboratory facilities

Variables:
Light: Timing, duration
Human: (laboratory animals:) agonistic behaviour, hormones (corticosterone), without daylight

The dynamic system
"After the first week the artificial light–dark cycle was 12:12 with lights on at 07:00h. The second cohort of mice was kept with this 12:12h light–dark cycle from the start. Half of each cohort received environmental enrichment." (23. p. 378).

"[…]shows the importance of a semi-natural light–dark cycle - No effects of enriched housing were found. This experiment has shown that disturbed lighting for socially-housed male mice caused physiological and behavioural changes indicative of stress, not only leading to much higher levels of corticosterone but also to shorter agonistic latency within the groups. […] Both the genetic background and the environment influence biological responses." (ibid., p. 380-381).

Published:
2014

Article:
A light/dark cycle in the NICU accelerates body weight gain and shortens time to discharge in preterm infants

Field of science:
Medical science

Objective:
"Bright constant light levels in the NICU may have negative effects on the growth and development of preterm infants Objective: The aim of this study is to evaluate the benefits of an alternating light/dark cycle in the NICU on weight gain and early discharge from the therapy in premature infants." (24, p. 535).

Target group/ Context:
Premature infants, Neonatal intensive Care Units (NICU)

Variables

Light: x
Human: Growth, length of hospitalization

The dynamic system
The LD condition was achieved by placing individual removable helmets over the infant's heads. In the NICU background lighting at the level of the incubators was 249 ± 11 lux, with light provided by overhead fluorescent white lamps. Control LL infants were exposed to the daily CL conditions of the NICU. Infants to the experimental LD condition remained in the same room, but the LD condition was achieved by placing from19:00 to 07:00 an acrylic helmet (Adult Oxy-Hood of 30 cm diameter; IDEM, México), covered with blue surgical drapes (50×60 cm, Medline Industries. Inc. USA); the surgical cloths were placed on helmets, and the frontal part was open allowing good airflow (see Fig. 1). This helmet was placed individually above the head and thorax of each baby as shown in Fig. 1, resulting in a reduced illumination, with a light intensity of 27 lux±0.8 at the level of the eyes […]." (ibid., p. 536).
"Infants maintained in an LD cycle gained weight faster than infants in LL and therefore attained a shorter hospital stay, (34.37±3.12 vs 51.11±5.29 days; P N 0.01). Also, LD infants exhibited improved oxygen saturation and developed a daily melatonin rhythm. Conclusions: These findings provide a convenient alternative for establishing an LD environment for preterm healthy new-borns in the NICU and confirm the beneficial effects of an alternating LD cycle for growth and weight gain and for earlier discharge time. Here we provide an easy and practical alternative to implement light/dark conditions in the NICU." (ibid., p. 535).
"In summary, we found that exposing premature infants to a light/dark cycle improved physiological development, promoted a rapid weight gain, and especially decreased the hospital discharge time. The latter implies benefits for the baby who is quickly incorporated to the family and by leaving the hospital the risk of exposure to nosocomial diseases is reduced. Furthermore, the direct and indirect economic costs in health services are also reduced. Herewe provide an easy and practical alternative to implement light/dark conditions in the NICU." (ibid., p. 540).

Concept:

Light Pulse (LPu)

Published:
2016

Article:
Short Blue Light Pulses (30 Min) in the Morning Support a Sleep-Advancing Protocol in a Home Setting

Field of science:
Chronobiology

Objectives
Supporting modern lifestyle
"Light therapy in the morning is often proposed as the most effective method to advance the circadian rhythm and sleep phase. […] light therapy, can phase shift the sleep phase along with the circadian rhythm with preservation of sleep integrity and performance." (25, p. 483).

Key terms:
Sleeping out of phase (social jetlag):
"Sleeping out of phase with the external light-dark cycle, especially sleeping later, has become a common habit in our civilized society. Despite the fact that workdays and school days typically start early in the day, many people go to bed late and try to compensate for the sleep deficit by extending their sleep on free days." (ibid., p. 484).

Target group/ Application:
Social jetlag, home applicated

Fundamental elements (variables)

Light:	Intensity, spectral power distribution, time, duration, distance to eye,
Impetus:	Diurnal working rhythm
Human:	Sleep (subjective, non-visual effect), performance (objective, non-visual effect), melatonin

The dynamic system
"We found that 3 optimally timed light pulses of 30-min high-intensity blue light were able to shift the melatonin rhythm for about 50 min (Geerdink et al., 2012). Therefore, in this study, we used 30 min of light therapy, which is easy to comply within a home situation. Subjects were instructed to expose themselves to either 30 min of high-intensity blue light (Philips GoLite BLU HF3320, peak transmission at 470 nm, intensity at the cornea 2306 melanopic-lux [Lucas et al., 2014], 300 photopic lux, 3.0 W/m2) at a distance of 40 cm and angle of exposure of 45°) or to control 30 min of amber light with similar photopic illuminance (adapted Philips GoLite HF3320, peak transmission at 590 nm, intensity at the cornea 70 melanopic-lux, 250 photopic lux, 0.5 W/m2). Timing of the light pulse was based on the subjects' habitual sleep schedule during baseline days 4 to 10 measured by actigraphy and on the subjects' preferred timing of sleep after the treatment. The last 3 light pulses were set at the preferred sleep offset, and the timing of the light exposure was set 1 h earlier every 3 days. To get sufficient sleep, sleep timing was scheduled to shift along with the light therapy." (ibid., p. 487).
"This study shows that blue light therapy in the morning, applied in a home setting, supports a sleep advancing protocol by phase advancing the circadian rhythm as well as sleep timing.
Keywords." (ibid., p. 484).

Concept:
Light Therapy (LTh)

Published:
2015

Article:
Bright white light therapy in depression: A critical review of the evidence

Field of science:
Psychology

Objective:
Circadian entrainment, psychological health
To critically evaluate treatment effects of bright white light (BWL) on the depressive symptoms in both SAD and non-seasonal depression.

Key terms:
Bright White Light
([…] bright white light administered in the morning on the depressive symptoms in both SAD and non-seasonal depression. (26, p. 2).

Target group/ Context:
SAD patients, no specific context

Variables:

Light:	Intensity, time
Impetus:	Biological circadian treatment
Human:	Symptoms of SAD

The dynamic system:
"Use of morning bright white light (BWL) as one of the treatment alternatives. […] Bright light studies have used an illumination of 2500–10,000 lx in the treatment alternative presumed to be the active one." (ibid., p. 5).

"Most studies of BWL have considerable methodological problems, and the results of published meta-analyses are highly dependent on the study selection. Even though quality criteria are introduced in the selection procedures of studies, when the results are carefully scrutinized, the evidence is not unequivocal." (ibid., p. 1).

Published:
2005

Article:
Psychological health,
The Efficacy of Light Therapy in the Treatment of Mood Disorders: A Review and Meta-Analysis of the Evidence

Field of science:
Psychology

Objectives:
Psychological health, circadian entrainment
"[…] hypothesis about the pathophysiology of the syndrome (i.e., depressogenic effects of melatonin). which in turn shaped the selection of treatment parameters: the intensity, duration, and timing of bright light exposure were designed to suppress the release of melatonin and lengthen the photoperiod." (27, p. 565).

Target group/ Application:
SAD or non-seasonal depression

Fundamental elements (variables)

Light:	Intensity, time, duration,
Impetus:	Biological circadian treatment
Human:	Symptoms of SAD

How things function? (dynamic system)
"When we analyzed the data from all available randomized, controlled trials that met our a priori standards, we demonstrated a significant reduction in depression symptom severity following bright light therapy in seasonal affective disorder and in non-seasonal depression, as well as a significant effect with dawn simulation in seasonal affective disorder. In other words, when the "noise " from unreliable studies is removed, the effects of light therapy are comparable to those found in many antidepressant pharmacotherapy trials." (ibid., p. 660)

"Two studies by Rosenthal et al. (1, 12). Terman et al. (30) found that 2,500-lux light exposure for at least 2 hour s/day for 1 week resulted in significantly more remission when administered in the early morning than in the evening or at midday. Treatments at each of these three administration times were significant ly more effective than control treatments with dim light. Tam et al. (31) concluded that bright light therapy that utilized at least 2,500- lux whit e light for 2 hours/day and treatment with 10,000 lux for 30 minutes /day had comparable response rates and that both treatments were efficacious." (ibid.).

Concept:
Natural Lighting System (NLS)

Published:
2014

Article:
A natural lighting system using a prismatic daylight collector

Field of science:
Building Engineering

Objective:
Wellbeing, energy efficiency, working performance,
"[…] a natural lighting system composed of a tilted prismatic daylight collector, an outdoor reflector and an indoor diffuse reflector is described." (28, p. 534).

Key terms:
Natural lighting
"The concept of natural lighting is to bring daylight into the core areas of buildings. This has the benefit of reducing the use of artificial lighting and directly using solar energy without the losses that the transform- ation from solar energy into electrical energy involves. In general, natural lighting systems are composed of a daylight collector, for collecting daylight when sunlight is falling on it; a light guide through which the collected daylight is redirected by the optical compo- nents and an emission component for illuminating the core areas of a room." (ibid.).

Target group/ Context:
No specific target group, no specific context

Variables:

Light:	Intensity, daylight included
Impetus:	Daylight
Human:	Glare (subjective visual effect), performance (objective non-visual effect),

The dynamic system:
"Utilizing daylight for interior illumination can contribute to energy savings by reducing artificial light- ing use. Further, natural light illumination systems have the potential to improve human health, mood, performance and productivity.1–5" (ibid.).
"Anidolic daylighting systems collect daylight by non-imaging daylight collectors and pipe diffuse daylight into horizontal funnels for illuminating deep buildings.13,14 Because the amount of trans- mitted daylight varies with the position of the sun, hybrid systems of natural lighting coupled with artificial light sources or solar cells have also been developed." (ibid.).
"The natural lighting system described in this paper is composed of three separate components, an active tilted prismatic daylight collector which is mounted outside the building facade and above the window, a reflector under the collector that redirects the collected sunlight into the core of the room, and an indoor diffuse reflector for daylight illumination." (ibid., p. 535).
"The results show that tilted prismatic daylight collectors can deliver the majority of the emerging light from sunlight to illuminate the room and thus efficiently collect solar energy." (ibid., p. 546).

Concept:

Natural Light Reproduction System (NLRS)

Published:
2015

Article:
Design and Implementation of the Natural Light Reproduction System Based on Context Awareness in WSN

Field of science:
Building science, Computer science and engineering

Objective:
Wellbeing, energy efficiency, circadian entrainment, psychological and physiological health
"Changes in natural light in the daily cycle and monthly cycle and its seasonal changes create rhythms in bodies of living creatures including humans. The circadian rhythm connected to natural light stimulates psychological states and hormonal changes. As such, natural light is a major environmental factor that affects humans' psychological and physiological conditions. To create healthy and comfortable lighting environments in windowless space such as a basement where no natural light can enter, the daily, monthly, and seasonal cycles of natural light need to be represented by means of artificial lightings. Upon certain situations related to purposes of space and user behaviors, lighting control technology is required for appropriate lighting environments." (29, p. 1).

Key terms:
Conformity with natural light
"The conformity of color temperature of each case was compared with that of natural light by means of a scatter plot (see Figure 18).As a result, the fixed output of Case A showed a low relation between artificial lighting color temperature and natural light color temperature (Figures 18(a)–18(f)), while Case C, suggested in this study, showed a low level of correlation (correlation coefficient 퓢2:0.4437) and Case B showed a high level of correlation (퓢2:0.7722).In short, the natural light color temperature system of Case B showed superior performance than Case C, the suggested system, and Case A, which was a fixed output system, in terms of conformity with natural light color temperature." (ibid., p. 14).

Target group/ Context:
No specific target group, indoor appliance – without access to daylight

Variables

Light:	Energy-saving effect, conformity with natural light
Impetus:	Diurnal working rhythm, activity, daylight
Human:	Behaviour (subjective, visual effect), appreciation

The dynamic system:
The scenarios were selected for each time period in connection with the behaviors of the seller who resided there for a long time. The suggested system's performance was evaluated in terms of conformity with natural light, comfort, and energy-saving effect

to enhance the psychological and physiological conditions of an inhabitant residing in a windowless space such as an underground space with no natural light for a long period of time. By dynamically controlling lighting environments depending on an occupant's situation and in reflection of the daily cycle of natural light, this system provides a user with a healthy and comfortable condition. To

four situations "Working," "Dining," "Daily Routine," and "Selling" were defined, with each situation being recognized by sensors. The

Lastly, to evaluate the suggested system's performance, the lighting control systems were classified into three major types: Case A, the existing system of fixed output; Case B, a system that represents the daily cycle of natural light; and Case C, a system that provides natural light characteristics appropriate for an occupant's situations. The performance of each system was then comparatively analyzed in terms of "conformity with natural light," "comfort," and "energy." As a result, it turned out that the suggested system, Case C, showed a normal level of conformity with natural light and a superior level of comfort and energy efficiency. In other words, all of the lighting environments simulated according to the scenario showed a level of illuminance and a color temperature corresponding to the “Comfortable” area in Kruithof ’s curve. This system maximized a user’s convenience by interpreting the situations based on the information collected by sensors without any need for a user’s intervention.

Concept:
Personalized Control (PC)

Published:
2015

Article:
Personal environmental control: Effects of pre-set conditions for heating and lighting on personal settings, task performance and comfort experience

Field of science:
Building science

Objective:
Wellbeing, energy efficiency, working performance,
"The aim of the study was to evaluate the effect of pre-set environmental conditions of temperature and lighting on the preferred personal settings of office workers and the consequences of this on comfort and task performance." (30, p. 166).

"Increased personal control over the environment conditions may be realized by providing just acceptable environmental conditions on general level combined with personal fine-tuning on local workstation level. In order to identify the potential of such a local individually controlled environment, in terms of user benefits as well as energy use, there is a need for clarity on aspects of human system interaction. To define design characteristics, important for application in practice, information is needed about the office workers' interaction with and response to the system (i.e. the values office workers choose), and how it affects their work performance and comfort experience." (ibid., p. 167).

Key terms:
Personal environmental control
"Hedge et al. [6] distinguish between real personal control (the availability and the ease of use of the aspects that one can modify in the physical environment) and the experienced control (the experienced per- sonal influence, the importance of the impact and consequences of the use of this influence). The interaction with the environment is an essential part and various factors such as behavior, attitude, design and ease of use play a role in the actual and proper use of individually controlled environments." (ibid.).

Intelligent Building
"One of the concepts of 'Intelligent Building research', as formulated by Cole and Brown [16], is using information and communication technology to provide 'occupant intelligence', wherein a building explicitly enables its users to make appropriate adjustments in their local environmental conditions and at the same time providing and maintaining operational efficiencies in energy use. The essence of intelligent building concepts is that on all the settings of light, climate, sound and atmosphere, the greatest possible shift is pursued from averaged, spatial settings to individual, local settings." (ibid.).

Target group/ Context:
Working environment

Variables

Light:	Intensity, correlated colour temperature, energy consumption
Impetus:	Individual need,
Human:	Preference, performance (objective, visual effect)

The dynamic system:
"The experimental setup contained direct and indirect lighting. […] The local lighting system was mounted above the desk (2 m above the floor) and consisted of 6 dimmable TL light tubes: 3 in an armature directed upwards, providing the indirect lighting in the room, and 3 in an armature directed downwards, providing the direct lighting on the desk. The direct illuminance and the indirect illuminance in the work space together resulted in the illuminance level on the desk.

They were also able to adjust the direct illumination level by pushing a “plus” or “minus” button on a computer screen, without knowing the actual illuminance and without knowing the range.” (ibid., p. 168).

“Providing personal environmental control and the way these concepts and the interfaces are designed seem to play a significant role in user behavior and preferences. The design and control of individually controlled workstations as well as the interaction with the general level of the office environment should be carefully considered in order to obtain maximum comfort and energy efficiency.“ (ibid., p. 167).

Concept:
Phototherapy

Published:
2016

Article:
Shedding a Light on Phototherapy Studies with People having Dementia: A Critical Review of the Methodology from a Light Perspective

Field of science:
Medical science

Objective:
Circadian entrainment, psychological health
“This study reviewed light therapy studies concerning the effects on people with dementia as a way to check the methodological quality of the description of light from a light engineering perspective.” (31, p. 551).

Key terms:
Light therapy
“Light therapy is studied and used as a nonpharmacological treatment of a variety of health-related problems, such as the therapy for a variety of skin conditions,1 circadian rhythm- related problems,2-5 and mental conditions.6,7 It can be administrated in various ways, from exposure to daylight to exposure of light emitted from wall, ceiling, or table-mounted devices and luminaires.” (ibid.).

Drug
“When engaging in pharmacological research and testing new drugs on human beings, it is of the utmost importance to know the exact substance and the exact doses in which this substance is administered to a research participant or patient. In the case of light therapy, people are being exposed to a type of radiation (light), which can be compared to administering pills that are either a placebo or contain ibuprofen, paracetamol, or aspirin in unknown doses. Light therapy without an adequate description of the equipment and characteristics of the exposure is like doing pharmacological research of which the methodology section only states ‘‘we tested a pill.’’ (ibid., p. 552).

Target group/ Context:
People suffering from dementia, SAD, Non-seasonal depression, skin problems (psoriasis) etc., nursing homes, elderly

Variables:
Light: Intensity, correlated colour temperature, not spectral distribution (criticized), distance to eye, time, duration, colour rendering index, daylight included
Impetus: Circadian biological rhythm
Human: Circadian system, sleep, depression symptoms cognitive performance (objective, non-visual effect),

older people with dementia as a target group. This type of light therapy aims to improve the cognitive behavior and to enhance the extent of behavioral symptoms by exposure to (high) levels of (ambient) light aiming to reset a free-running biological clock. Studies on any form of light therapy on (older) people with dementia12-17 found a number of short- and long-term effects: a more stable sleep–wake rhythm, improvement in rest- less and agitated behavior, and beneficial effects on the cogni- tive functioning.

The dynamic system
“The majority of studies were conducted using light boxes, in particular, table-mounted devices. […] daylight was also considered to be therapeutic. In the study of Riemersmavan der Lek et al,35 ambient bright light is used.
Results from studies focusing on the effects of light therapy will be used for the improvement and further development of products and building design. This requires a proper coordination and translation of input and output data. We know that light for non-image forming effects follows a different pathway and procedure in the human brain than for the

formation of images (visual). The rods and cones, related to image-forming effects, are connected to the visual cortex in the brain. They have a direct response and are most sensitive to 507

Concept:
Pulsating Light (PL)

Published:
2017

Article:
Atmosphere perception of dynamic LED lighting over different hue ranges

Field of science:
Computer science and technology

Objective:
Wellbeing, technical exploitation,
"As one of the major features of LED-based lighting, the affective effects of dynamic lighting need more attention." (32, p. 2).

Key terms:
Colour fluctuation speed
"[…] adding slow pulsations to some coloured lighting might support stress-reduction while creating a relaxed atmosphere. Wang et al. studied the atmosphere of full hue-range colour-varied dynamic lighting and extracted three atmosphere factors: tenseness, coziness and liveliness." (ibid.).

Atmosphere:
"Atmosphere is the experience of ambient surroundings in relation to observers. They also developed a metric to measure the atmosphere perception, and extracted two factors as coziness and liveliness." (ibid.).

Target group/ Context:
No specific target group, No specific context.

Variables

Light:	Intensity, colour, atmosphere, transition speed (smoothness)
Impetus:	Continuous rhythm
Human:	Perception, preference subjective, visual effect)

The dynamic system:
"When an experiment started, the light conditions were displayed one by one in random sequence. Every light condition included three phases. Phase 1 was 10 seconds neutral light (luminance: 68 cd/m2, 6500K) for the observers to prepare. Phase 2 was 45 seconds26 of experimental light. To help observers accommodate, they were asked to build certain forms with 100 wooden blocks placed on the table. A sound signal rung at the end of this phase. Phase 3 was to answer the questionnaire with the experimental light- ing displaying." (ibid., p. 6).

"Speed positively affected the perception of fast, romantic, lively, attached and luxurious; however, negatively affected the perception of formal, spacious, comfortable, safe and urban. […]The 'natural– artificial' perception was affected by luminance, chroma and speed. As chroma decreased, speed decreased, or luminance increased, the atmosphere was felt to be more" (ibid., p. 8).

Published:
2012

Article:
The Influence of Lighting Color and Dynamics on Atmosphere Perception and Relaxation

Field of science:
Human technology interaction

Objective:
Wellbeing, mental health
“An environment can support stress restoration and improve the effectiveness in facilitating stress coping (Ulrich, 1991). Ulrich (1991) suggested that the physical environment can provide positive distractions (e.g., music in a hospital)” (33, p. 1).

Key terms:
Positive distraction
“Ulrich (1991) suggested that the physical environment can provide positive distractions (e.g., music in a hospital) that elicit positive feelings and holds attention and interest without taxing or stressing the individual, and thereby may block or reduce worrisome thoughts. Similarly, we argue that slow but perceivably changing dynamic lighting may serve as a positive distractor and thereby reduce stress levels.” (ibid.).

Target group/ Context:
No specific target group, no specific context

Variables

Light:	Colour, intensity, transition speed (smoothness)
Impetus:	Continuous rhythm
Human:	Perception, psychological and physiological measurements of stress: anxiety, heart rate etc

The dynamic system:
“A pretest was conducted to investigate the appropriate settings for the lighting stimulus. The results of this pretest suggested that an orange colored lighting setting with medium paced (.125 Hz) pulsations was the most preferred for relaxation. This lighting setting varied in saturation, whereas the white colored lighting condition varied in intensity” (ibid., p. 2).

“Results provided no evidence that, overall, orange lighting leads to lower stress levels (neither psychological nor physiological), nor that orange lighting in general leads to lower stress levels than white lighting. However, results did suggest that orange and pulsating, and also static white lighting leads to lower psychological stress levels than static orange or pulsating white lighting. Furthermore, in line with earlier findings, results suggested that orange lighting conditions created a more relaxed (more cozy, less detached) atmosphere than white lighting conditions.” (ibid., p. 3).

Concept:
SmartHeliosity

Coined:
2011

Article:
SmartHeliosity: Emotional Ergonomics through Coloured Light

Field of science / Key theory
Design

Objectives
Wellbeing, technical exploitation
"SmartHeliosity prototype which evaluates human emotions to provide appropriate coloured light in order to enhance emotional wellbeing within the working environment." (46)

Key terms:
Colour therapy
"Colour therapy or sometimes called chromotherapy is an established alternative medicine method" (ibid., p. 226).
"Light and colour can be used for creating or inducing certain emotions or moods for specific situations. Axel Venn [7] shows that certain colour combinations imply certain feelings. In a survey with more than 60 participants, 1625 colours of the RAL design system have been connected to more than 360 feelings and adjectives." (ibid., p. 228).

Target group/ Application:
No specific target group, office environment

Fundamental elements (variables)

Light:	Colour,
Impetus:	Individual need (IoT), emotions
Human:	Mood,

How things function? (dynamic system)
"SmartHeliosity aims at inducing positive emotions by providing an adaptive mood light. Our system evaluates human emotions and controls a colour changing light based on this information, with the aim to enhance the emotional well-being within the working environment." (ibid., p. 226).

"SmartHeliosity is flexible in two respects: the material itself is flexible and can be bent in various shapes, and several single tiles can be connected to each other to build a modular light sculpture in various forms and sizes. It can be adapted to the environment and to the preferences of the user. One module is shown in figure 5. Figure 7 shows four separate modules that can be connected to each other. Several modules can be joined together in any numbers to create different patterns in 3 dimensional spaces. LED stripes are embedded in silicone. The aluminium wire mesh allows for bending and forming the structure to the desired shape. The silicone protects the LEDs and holds the structure together. The flexible LED stripes are endowed with RGB 120° viewing angle PLCC2 SMD LEDs. They are driven with 12V and have a luminous flux of 800 lm. The LEDs are controlled by a 12 channel 16 bit DMX dimmer [11]. The transformation from the computer signal to the DMX values is realized by an Ethernet / DMX512 Control Box [12]." (ibid., p. 232).

"The technical realization of the SmartHeliosity concept is based on the integration of various already available sources of information about the working environment and the user as well as an adaptive LED-luminaire. The luminaire is flexible and can be adapted to the environment and to the preferences of the user in size and form like a modular sculpture. It is made of LEDs embedded in silicone. Each module is like a "Lego" which can be joined together in any numbers to create different patterns in three dimensions. This gives flexibility to the user to have its own light sculpture. As already mentioned, the detected emotions are linked to a colour database. Our software provides light algorithms to tune to the emotions of the user." (ibid., p. 230).

algorithms continuously calculate appropriate colour combinations to suite emotion of the user. Basically we try to provide a light condition to bring the user's emotional level to the desired and appropriate condition. Whenever some negative emotions are induced, such as angriness, annoyance or sadness, it tries to normalize it to well being conditions like relaxed and calm conditions. Whenever positive emotions are detected it tries to maintain them at a certain level and not to go into hyper emotional conditions. Figure

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Concept:
Smart Lighting

Published:
2016

Article:
Orchestrating light – Gesture-based control of smart lighting

Field of science / Key theory
Human-Technology Interaction

Objective:
Technical exploitation, individualization,
"Modern smart environments are equipped with a multitude of devices and systems with an increasing number of features.6 Controlling such functionality is a challenge on user controls. Switches and remote controls typically applied in lighting become more and more complicated and inconvenient to the user.7 Gestures and vocal controls would provide an intuitive method to communicate with smart systems." (35, p. 1).

Target group/ Context:
No specific target group, office environment

Variables:

Light:	Colour, intensity
Impetus:	Individual need (manual and IoT), movement, hand gesture
Human:	Motivation, preference

The dynamic system
"One or more luminaires can be selected for light adjustment by pointing at the desired luminaires with a hand. Deselecting already selected luminaires can be done in a similar fashion. The user can control brightness by moving the pointing hand in a vertical direction. The higher the user points with a hand, the brighter the luminaires are set. Similarly, the colour value can be controlled by tilting the pointing hand in a vertical direction. For this demonstrator, we selected an angle space of 120 degrees in a vertical direction which was mapped into the hue-space going through colour values from red to blue and additionally a white colour beyond 120 degrees. However, the colour-to- angle mapping can be chosen differently and is not limited to the selection made in this study. When the user is satisfied with the selected colour and brightness values, the adjusted settings can be set permanently by relaxing the pointing hand and waiting until the adjustment timer expires." (ibid., p. 6).

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1. Greenhalgh T, Peacock R. Effectiveness and efficiency of search methods in systematic reviews of complex evidence: Audit of primary sources. Br Med J. 2005;331(7524):1064–5.
2. Aries MBC. Human Lighting Demands, healthy lighting in an office environment. Technische Universiteit Eindhoven. 2005. 158 p.
3. Avery DH, Eder DN, Bolte MA, Hellekson CJ, Dunner DL, Vitiello M V., et al. Dawn simulation and bright light in the treatment of SAD: A controlled study. Biol Psychiatry. 2001;50(3):205–16.
4. Gabel V, Maire M, Reichert CF, Chellappa SL, Schmidt C, Hommes V, et al. Effects of Artificial Dawn and Morning Blue Light on Daytime Cognitive Performance, Well-being, Cortisol and Melatonin Levels. Chronobiol Int. 2013;528.
5. Thorn L, Hucklebridge F, Esgate A, Evans P, Clow A. The effect of dawn simulation on the cortisol response to awakening in healthy participants. Psychoneuroendocrinology. 2004;29(7):925–30.
6. Yngve Petersen K, Søndergaard K, Kristensen O, Augustesen C, Rask N. Energioptimering gennem adaptiv lysstyring. 2017.
7. Brawley EC. Enriching lighting design. NeuroRehabilitation. 2009;25:189–99.
8. B. Saletu, M. Dietzel, OM. Lesch, M. Musalek, H. Walter JG nberge. Effect of Biologically Active Light and Partial Sleep Deprivation on Sleep, Awakening and Circadian Rhythms in Normals. method whereby one tries. 1986;25(2):82–92.
9. Kim YJ, Kwon SY, Lim JH. Design and Implementation of the Natural Light Reproduction System Based on Context Awareness in WSN. Int J Distrib Sens Networks. 2015;2015.
10. Woelders T, Beersma DGM, Gordijn MCM, Hut R a., Wams EJ. Daily Light Exposure Patterns Reveal Phase and Period of the Human Circadian Clock. J Biol Rhythms. 2017;32(3):274 –286.
11. Wahnschaffe A, Haedel S, Rodenbeck A, Stoll C, Rudolph H, Kozakov R, et al. Out of the lab and into the bathroom: Evening short-term exposure to conventional light suppresses melatonin and increases alertness perception. Int J Mol Sci. 2013;14(2):2573–89.
12. Vetter C, Juda M, Lang D, Wojtysiak A, Roenneberg T. Blue-enriched office light competes with natural light as a zeitgeber. Scand J Work Environ Heal. 2011;37(5):437–45.
13. Geerdink M, Walbeek TJ, Beersma DGM, Hommes V, Gordijn MCM. Short Blue Light Pulses (30 Min) in the Morning Support a Sleep-Advancing Protocol in a Home Setting. J Biol Rhythms. 2016;31(5):483–97.
14. Jou J-H, Chen P-W, Hsieh C-Y, Wang C-C, Chen C-C, Tung F-C, et al. Candle light-style OLED: a plausibly human-friendly safe night light. 2013;8829:88291B.
15. Bonmati-carrion MA, Arguelles-prieto R, Martinez-madrid MJ. Protecting the Melatonin Rhythm through Circadian Healthy Light Exposure. Int J Mol Sci. 2014;15:23448–500.
16. Jusl??n H, Tenner A. Mechanisms involved in enhancing human performance by changing the lighting in the industrial workplace. Int J Ind Ergon. 2005;35(9):843–55.
17. Hansen EK, Nielsen SML, Georgieva D, Schledermann KM. The Impact of Dynamic Lighting in Classrooms. A Review on Methods. In: International Conference on ArtsIT, Interactivity and Game Creation. Springer, Cham; 2018. p. 479–89.
18. Volf C. Light Achitecture and Health - a Method. Aarhus School of Architecture; 2013.
19. Kuijsters A, Redi J, De Ruyter B, Seuntiëns P, Heynderickx I. Affective ambiences created with lighting for older people. Light Res Technol. 2015;47(7):859–75.
20. Sekulovski D. Studies in ambient intelligent lighting Studies in Ambient Intelligent Lighting. 2013.
21. Targeted S. Ambient Lighting Assistance for an Ageing Population. 2009;(June 2009):1–44.
22. Saletu B, Dietzel M, Lesch, O M, Musalek M, Walter H, Grünberger J. Effect of biologically active light and partial sleep deprivation on sleep, awakening and circadian rhythms in Normals. Eur Neurol. 1986;25:82–92.
23. Grünberger J, Linzmayer L, Dietzel M, Saletu B. The effect of biologically-active light on the noo- and thymopsyche and on psychophysiological variables in healthy volunteers. Int J Psychophysiol. 1993;15(1):27–37.
24. Jou J-H, Hsieh C-Y, Chen P-W, Kumar S, Hong JH. Candlelight style organic light-emitting diode: a plausibly human-friendly safe night light. J Photonics Energy. 2014;4(1):43598.
25. Rea MS, Figueiro MG, Bierman A, Bullough JD. Circadian light. J Circadian Rhythms. 2010;8(1):2.
26. Estrup S, Kjer CKW, Poulsen LM, Gøgenur I, Mathiesen O. Delirium and effect of circadian light in the intensive care unit: A retrospective cohort study. Acta Anaesthesiol Scand. 2017;1–9.
27. Huffman Brandon D. The effect of cycled light versus continuous near darkness on growth and development of preterm infants born at less than 31 weeks gestation. University of North Carolina; 2000.
28. Danilenko K V., Ivanova IA. Dawn simulation vs. bright light in seasonal affective disorder: Treatment effects and subjective preference. J Affect Disord. 2015;180:87–9.
29. Gabel V, Maire M, Reichert CF, Chellappa SL, Schmidt C, Hommes V, et al. Effects of artificial dawn and morning blue light on daytime cognitive performance, well-being, cortisol and melatonin levels. Chronobiol Int.

2013;30(8):988–97.
30. Erren TC, Reiter RJ. Light Hygiene: Time to make preventive use of insights – old and new – into the nexus of the drug light, melatonin, clocks, chronodisruption and public health. Med Hypotheses. 73:537–41.
31. de Kort Y, Smolders K. Effects of dynamic lighting on office workers: First results of a field study with monthly alternating settings. Light Res Technol. 2010;42(3):345–60.
32. Lowden A, Åkerstedt T. Assessment of a New Dynamic Light Regimen in a Nuclear Power Control Room Without Windows on Quickly Rotating Shiftworkers—Effects on Health, Wakefulness, and Circadian Alignment: A Pilot Study. Chronobiol Int. 2012;29(July 2011):641–9.
33. Aarts MPJ, Aries MBC, Straathof J, Hoof J van. Dynamic lighting systems in psychogeriatric care facilities in the Netherlands: A quantitative and qualitative analysis of stakeholders' responses and applied technology. Indoor Built Environ. 2015;
34. Aries MBC. Human Lighting Demands, healthy lighting in an office environment. Technische Universiteit Eindhoven 2005. 2005. 158 p.
35. Boyce PR. Editorial : Exploring human-centric lighting. Light Res Technol. 2016;48(2):Editorial.
36. Shaw K, Eng MILP C, Design Director L. Lighting Design for Health, Wellbeing and Quality of Light, A Holistic Approach on Human Centric Lighting. 2016.
37. Van der Meer E, Van Loo PLP, Baumans V. Short-term effects of a disturbed light–dark cycle and environmental enrichment on aggression and stress-related parameters in male mice. Lab Anim. 2004;38(4):376–83.
38. Vásquez-Ruiz S, Maya-Barrios JA, Torres-Narváez P, Vega-Martínez BR, Rojas-Granados A, Escobar C, et al. A light/dark cycle in the NICU accelerates body weight gain and shortens time to discharge in preterm infants. Early Hum Dev. 2014;90(9):535–40.
39. Mårtensson B, Pettersson A, Berglund L, Ekselius L. Bright white light therapy in depression: A critical review of the evidence. J Affect Disord. 2015;182:1–7.
40. Robert N, Bradley N, David R, Robert M, Gaynes BN, Ekstrom RD, et al. The Efficacy of Light Therapy in the Treatment of Mood Disorders: A Review and Meta-Analysis of the Evidence. Am J Psychiatry. 2005;162(4):656–62.
41. Yeh S-C. A natural lighting system using a prismatic daylight collector. Light Res Technol. 2014;46:534–47.
42. De Korte EM, Spiekman M, Hoes-van Oeffelen L, van der Zande B, Vissenberg G, Huiskes G, et al. Personal environmental control: Effects of pre-set conditions for heating and lighting on personal settings, task performance and comfort experience. Build Environ. 2015;86:166–76.
43. Aarts MPJ, Aries MBC, Diakoumis A, van Hoof J. Shedding a Light on Phototherapy Studies with People having Dementia: A Critical Review of the Methodology from a Light Perspective. Am J Alzheimers Dis Other Demen. 2016;6(7):1533317515628046-.
44. Li B, Zhai Q, Hutchings J, Luo M, Ying F. Atmosphere perception of dynamic LED lighting over different hue ranges. Light Res Technol. 2017;147715351770253.
45. Wan SH, Ham J, Lakens D, Weda J, Cuppen R. The Influence of Lighting Color and Dynamics on Atmosphere Perception and Relaxation. Exp Light 2012. 2012;1–4.
46. Stefani O, Mahale M, Pross A, Bues M, Design I. SmartHeliosity : Emotional Ergonomics through Coloured Light. Ergon Heal Asp. 2011;226–35.
47. Myo P, Ha J, Pentika V. Orchestrating light – Gesture-based control of smart lighting. Light Res Technol. 2016;1–23.

See additional literature in doc. 'dynamic concepts'

Working Paper 2:

State-of-the-Art

This state-of-the-art chapter (SOTA) covers the rationale behind the projects objective to (a) investigate how dynamic lighting can be considered from a spatial context and b) test the health, well-being and performance potentials associated with this quality. The SOTA is therefore divided into the following sections: The potential in subjective well-being and performance; The spatial distribution of lighting; Transdisciplinary field studies of lighting.

The potential in subjective well-being and performance

Studies investigating dynamic lighting in relation to human health and well-being are often performed in laboratories where test subjects are exposed to light under unnatural conditions - for short period of time, excluded from daylight and sleep deprived (1-15). In these studies, the typical photometric variables' effects on the human body and psyche are studied in controlled environments. In field studies, however, or laboratory that seek to simulate complex real-world environments, the results aren't always confirming the results from lab tests. It is often argued, that even small amount of daylight has a compromising effect on results obtained in laboratories (28-30) This imposes certain limitations on results obtained in laboratories (20), and especially the effect on physiological and objective parameters. Studies shows that the effect on subjective psychological parameters is more consistent across laboratory and field studies (31, p. 80). When comparing the dynamic lightings effect on respectively objective and subjective parameters, Studies shows that a similar or greater effect can be demonstrated on subjective / psychological parameters compared to objective / physiological parameters – notably when studied in complex real-world environments (2,17,28,31-33). Another interesting example to emphasize is light therapy, that compares the effect of strong blue / white light with the effect of a simulated sunrise on Seasonal Affective Disorder (typical cognitive performance, mood, well-being, cortisol and melatonin levels). Where the blue and white light seeks to copy the photometrical qualities of the daylight (short-waved radiation), the simulated sunset seeks to imitate the experienced effect of a natural light phenomenon (varying colored light). Here the results indicate that simulated sunrise has a corresponding (16) or even greater effect (17-19). It could therefore be said, that the wellbeing and performance potential of dynamic illumination also depends on its experience quality. Despite that 'Soft values' such as perception, aesthetics, mood not always are highly regarded as much as 'hard values', health, performance, effectivity etc. in natural science and the industry, there are studies that investigate a linked-mechanism effect (originally developed by David Wyon, 34) between "the appreciation of lighting" and mood, and the perception of self-competence and thus motivation for task-solving, which ultimately increases performance (12,20,35-37). This 'linked-mechanism effect' is in line with a major literature study that, based on more than 280 articles, concludes that a direct effect between the physical environment and our mental health and capital can rarely be demonstrated (38). The study points out that it is rather a mediating and nonlinear relationship and that future research should take into account this complex relationship between human and environmental factors and explore the importance of intervening variables (ibid., P. 971) uddyb.

Interim summary: A) Previous studies can demonstrate that the effect of the experienced quality of lighting has a considerable impact on our well-being and performance, and emphasizes the importance of considering the experienced quality of the lighting in research as well as practice. B) The relationship between the experienced quality of lighting and the experienced health, well-being and performance is complex, nonlinear and should also be investigated through intervening variables.

The spatial dimension

Considering the current evidence that documents the positive effect of the experienced quality of dynamic lighting on well-being and performance, it could be interesting to look at other than the typical photometric variables - brightness and colour.

There are some examples of studies that have investigated the light's distributed in a spatial context (the spatial quality of the lighting) (21 p.14) and the impact it has on human well-being and performance. Jennifer Veitch et al. pioneered with a series of studies of lighting and its: "Appearance of the Space and Architectural Integration" (10,12,20 p.1). In addition to demonstrating positive effects on a variety of health, wellbeing and performance parameters, these studies also demonstrate an operationalization of the 'spatial qualities' of the lighting. Based on a variety of luminaire typologies, light scenarios are developed by professional light designers after respectively 'standard practice' and 'best practice'. Veitch associates hypotheses for individual light scenes and tests them according to Wyon's 'linked-mechanism-effect' model. What can be deduced from these studies is that the 'spatial qualities' of the lighting have an influence on the perception, well-being and performance. However, because Veitch et al. bases the operationalization of spatial qualities on luminaire typologies, it is difficult to derive a set of general spatial qualities that can be investigated in other contexts. For instance, in a dynamic context.

The perceived spatial distribution of lighting

Interim summary: C) There is a need to develop a conceptual framework/basic principles for the spatial quality of lighting, which may not be limited by contemporary design practices, standards or fixtures. This could, for example integrate architectural theoretical research. C) The mentioned studies by Veitch concludes that the spatial quality of lighting has biggest effect on perception/preference, experienced well-being and experienced performance. These parameters can advantageously be continued in present study to allow comparison of results.

Looking at the studies of light in architectureal research, there are a number of examples of phenomenological studies of light in a spatial context. Ulrika Wänström Lindh has studied how lighting influences our perception of space and creates different experiences of an illuminated environment: "The importance of visual spatial boundaries and brightness patterns are discussed in relation to enclosure, perceived dimensions and atmosphere" (24 p. 1).

Merete Madsen has developed a concept and tool to address the spatial qualities of daylight and categorizes them according to how they appear: "bubbles, spheres or areas of light, which can be compressed, expanded, combined, exploded, etc., all according to the character of "the meeting" between light zones and the space itself "(25 p.10). Carlo Volf has developed a method of investigating and documenting the changeable daylight in a spacious context in relation to geographic orientation of daylight openings and time (26). Nanet Mathiasen examines the characteristic of the Nordic light and how it manifests itself in the Nordic architecture (27). Kjell Y. Petersen et al. has developed an adaptive lighting concept that, in addition to the user's "life practices" and energy resources, integrates the ambience of the light: "Ambient light is evident, it gives light and shape to space and presence, but is not clearly distinguishable as single elements. "(39 p.18). Petersen is inspired by Ulrik Schmidt's conceptual definition of the ambiance of light (ibid., Pp. 59-60), which deals with the light's ability to draw space, wrapping, dynamics, zoning and the sensing body in the light (40). Based on these studies, it can be deduced that architectural research has partly examined how the distribution of lighting in a spatial context is visually perceived and affects our perception of space and atmosphere (23,24,39-41), how spaces can be registered and classified (25) are characterized (27) and how they can be documented (26).

Interim summary: D) Based on architectural research of the spatial qualities of light, a number of spatial principles and hypotheses about the associated properties can be generated. E) These spatial principles can enable a systematic study of their health and well-being characteristics in a dynamic context.

Transdisciplinary Field Studies

Previous studies have in their choice of methods endeavored to embrace the complex relationship between human and environmental factors. In Veitch and Boyce studies of the spatial qualities of lighting (10,12,20) it is demonstrated how light researchers apply transdisciplinary methods to embrace the complex relationship between human and environmental factors. The same article discusses the limitations of a laboratory experiment, including the short duration of the experiment on the same subject (max two days) and lacking important elements from a natural environment (e.g. daylight and different types of activities over time). This is considered to be limiting in the prediction of long-term effects as well as to the effects in different situations in relation to time (ibid., Pp. 149-150). Wyon concludes, based on his studies, that effects can diverge between laboratory and field studies - for example, the reduction in performance may be greater in practice than in realistic laboratory simulation trials (34). In a literature study by Hansen et al., who review methods used for light and learning studies, it is also concluded that field studies are more precise to predict the effect of light on humans and points to the importance of developing methods for holistic and transdisciplinary field studies (42 p.8). This resonates with the light designer's perception of light research, who believes that the results are often too complex and based on oversimplified light scenarios that do not match the challenges encountered in practice (43 p. 12). Werner Osterhaus, on this basis, argues that it is a significant challenge for light research to carry out studies in complex architectural contexts that can contribute with applicable knowledge (ibid.).

Interim summary: F) In order to study the spatial qualities of the lighting and the associated well-being potential, it should be considered to perform a field study over laboratory studies and for a longer period of time to demonstrate patterns over time (for example in relation to changing weather and seasons). G) Transdisciplinary studies that integrate methodology and theory from architecture and environmental psychology will enable us to draw conclusions that relate to complex and real-world environments demanded by the industry. On the other hand, this will also reflect previous research studies, which will allow comparison of results.

Working Paper 3:

Lighting Distribution

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1. Introduction

1.1. The 'experience-oriented' value

Working Paper 1 has uncovered, that 'dynamic lighting for health and wellbeing' research mostly is concerned with non-visual effects: 77.1% non-visual effects 22.9% visual effects (WP1, p. 6). Furthermore, Working Paper 2's review of dynamic lightings health and wellbeing potential, finds most evidence for visual effects that aims at psychological health (WP2, p. x). Furthermore, the review point towards, that dynamic lighting biggest potential is in the experience-oriented qualities. Despite this, the industry and academia mostly consider the dynamism of lighting in terms of intensity (96.2%), correlated colour temperature (42.3%) and brightness (WP1, appendix x). When considering the 'experinec-oriented' value of lighting and how it can influence the perception and experience of the world, it could be argued, that brightness and correlated colour temperature are insufficient to address, describe, evaluate a lighting environment's 'experience-oriented'- value.

1.2. Experienced distribution

The few lighting variables that emerges in WP1 analysis of 26 dynamic lighting concepts for health and wellbeing, which could be considered 'experience-oriented' are:

I. Beam characteristics and direction
II. Distribution
III. Architectural value

Three variables that all addresses the geometrical setting of lighting in a third-dimensional perspective. Furthermore, it could be argued, that they are the same variable in different contexts, where: I. is concerned with the volume of the lighting from a single light source; II. Is concerned with the volume of lighting in a spatial context; III. Is concerned with the volume of lighting in a building context.

in the field of architecture, the dynamic daylight has through history been recognized as one of the most powerful form givers in architecture. The importance of dynamic light has always been acknowledged as the primary medium, which puts man in touch with his environment [Lam, 1977]. Spaces influences our perception, emotions and our physical reactions [Sternberg 2009]. Dynamic light holds the potential of "adding excitement to architecture and provides opportunity for changing patterns of light and shadow on interior surfaces. It can give building occupants a sense of well-being, time and orientation" [Osterhaus]. The atmospheric aspects (including lighting); perception, mood and motivation are seldom considered in a holistic spatial design [Borch et al., 2014].

Present working paper (3) will review research that investigates the **experienced distribution** of lighting in space, and conclusively recommend how future research could go about expanding the way we address, describe and evaluate dynamic lighting to also include more 'experience-oriented'-

variables. Ultimately this could contribute to the way we design lighting environment to become more visually inspiring and more stimulating, and promote physical health and wellbeing.

1.3.Researchers reviewed

The experienced distribution of lighting in a spatial context holds the potential to affect our psychological health and wellbeing. To review what evidence has been produced so far, a number of researchers and their studies of lighting distribution have been selected and reviewed. Following psychologists has been selected:

Reviewed researchers:

- Jennifer Veitch (et al.)
- Kjell Yngve Petersen (et al.)
- Ulrika Wänström Lindh
- David Loe (et al.)
- Mariska G. M. Stokkermans (et al.)

Inclusion criteria for the chosen researchers, who has investigated the **experienced distribution** of lighting in space and its effects on human health and wellbeing: performance of practical and experimental studies that works through a conceptualization and operationalization of experienced distribution of lighting in space. Theoretical studies or studies of light without human subjects are excluded from this working paper.

1.4. Review of researchers

The individual researcher’s studies of the experienced distribution of lighting in a spatial context is reviewed in terms of:

2. Method

2.1. Methodical considerations

What do you do, when the subject investigated is complex, cross disciplinary, relatively young and in rapid development? In terms of searching for the most important paper on a given subject it is the predominantly assumption, that the review method should employ the most explicit and meticulous search strategy as possible. This assumption has been elaborated by Greenhalgh and Peacock, who distinguished between “simple” and “complex” evidence (1). Aforementioned method might be the most effective in terms of simple and quantitative studies, Greenhalgh and Peacock exemplifies: “In systematic reviews of clinical treatments, most high quality primary studies can be identified by searching four standard electronic databases”. But what Greenhalgh and Peacock adds to this is: “In systematic reviews of complex and heterogeneous evidence (such as those undertaken for management and policymaking questions) formal protocol-driven search strategies may fail to identify important evidence” (ibid., p. 1065).

As alternatives to the systematic reviews for investigating more complex and heterogeneous subjects, such as present subject: ‘dynamic lighting for health and wellbeing’, Greenhalgh and Peacock studies “sowballing” and “personal knowledge”. Snowballing is a review method, where the material is emerging as the study is unfolded. Practically it can be tracking of either references or citations, and

can be done either systematically through electronic search or by tedious tracking of interesting references and by judgement decide to follow up on these or not. Greenhalgh and Peacock concludes, that ""Snowball" methods such as pursuing references of references and electronic citation tracking are especially powerful for identifying high quality sources in obscure locations" (ibid.).
Even the very informal approach 'personal' knowledge can "substantially increase the yield and efficiency of search efforts" (ibid.), by browsing through other experts in the network, or being alert to occurring interesting material.

Greenhalgh and Peacock test the effectiveness and efficiency of all three search methods, in a comprehensive search including more than 6000 electronic abstracts. The result

5. *"Electronic searching, including developing and refining search strategies and adapting these to different databases, took about two weeks of specialist librarian time and yielded only about a quarter of the sources—an average of one useful paper every 40 minutes of searching.*

6. *It took a month to hand search a total of 271 journal-years, from which we extracted only 24 papers that made the final report—an average of one paper per nine hours of searching.*

7. *Overall, the greatest yield was from pursuing selected references of references. It was impossible to isolate the time spent on reference tracking since this was done in parallel with the critical appraisal of each paper.*

8. *Electronic citation tracking of selected papers took around a day in total and uncovered many important, recent sources, including five systematic reviews (three of which were not identified by any other method) and 12% of all empirical studies—around one useful paper for every 15 minutes of searching" (ibid.).*

Thus, Greenhalgh and Peacock points towards the gains of employing both systematic review that are purely protocol driven with supplementary methods, such as references tracking ("snowballing"), may be both more effective and efficient to uncover important sources that otherwise wouldn't have been found, no matter how many databases are searched with a protocol.

This working paper sets out to investigate 'experienced distribution of lighting for health and wellbeing', a subject that is investigated within many scientific fields and disciplines, that often possesses their own terminology. This engenders a complex and heterogeneous field, that hardly can be mapped and analysed through systematic literature review, without commonly used terms. This working paper have therefore employed supplementary search methods, in order to uncover more odious papers from more obscure journals, to achieve to find interesting researchers.

3. Results

3.1. Jennifer Veitch et al.

In a series of four articles, Jennifer et al. has been working with perceived lighting distribution as an element of quality lighting. Generally Veitch et al. builds on the 'Positive affect theory' (Isen & Baron, 1991), that: "suggests that working conditions do influence employees' well-being and work behaviors. […] positive affect might be a mediating mechanism for lighting effects on work behaviors but did not provide complete or clear guidance as to the lighting conditions that might be the most powerful triggers for positive affect." (2, p. 199).

Articles:

I. (1998) Lighting Quality and Energy-Efficiency Effects on Task Performance, Mood, Health, Satisfaction, and Comfort
II. (2006) Lighting quality and office work: two field simulation experiments
III. (2007) Lighting appraisal, well-being and performance in open-plan offices: A linked mechanisms approach
IV. (2011) Linking Lighting Appraisals to Work Behaviors

3.1.1. Problem

"We know the lighting conditions necessary to achieve high levels of visual performance and to avoid visual discomfort It is all too easy to find offices that are perceived to be gloomy and uninteresting, which has been the impetus behind the burgeoning research into lighting quality" (2, p. 191).

"the creation of attractive spaces that show architectural integration is less common. Lacking proof that lighting quality contributes to organisational productivity, the additional expense of thoughtful lighting design cannot be justified." (4, p. 133).

3.1.2. Objective/hypothesis

Veitch et al. are primarily concerned with addressing two hypotheses and two objectives:

- Hypothesis A: There is a linear relationship between lighting quality and health and wellbeing
- Objective A: To form a holistic definition of 'quality lighting' that holistically considers human health and wellbeing

In lack of a common definition of a holistic definition of quality lighting, Veitch et al. has attempted to conceptually frame and test: "to determine to what extent different levels of lighting quality, as understood by lighting designers, affect the performance, health and well-being. […] We had hypothesized that the behavioral outcomes would improve in a linear fashion with Designers' Lighting Quality." (3, p. 121).
"Most offices in the industrialized world enjoy conditions that are adequate to see visual tasks and that do not cause extreme discomfort to their occupants. However, questions remain as to the possibility that lighting conditions might be further improved beyond this minimum level, to the point at which they could become positive contributors to employee performance and well-being." (2, p. 199).

- Hypothesis B: The effects of lighting on health and well-being and on task performance are mediated by effects on other subjective and objective states
- Objective B: Tests of lighting conditions effects on the dependent measures directly

“These analyses address the proposition that the effects of lighting on health and well-being and on task performance are mediated by effects on other subjective and objective states.” (4, p. 134).

3.1.3. Terminology (keywords)

Lighting quality
‘Lighting quality’ (LQ) balances energy use level (environmental and resources) while still meeting immediate task, social, behavioural, aesthetic, emotional, health and safety needs. Veitch et al. proposes a behaviourally based definition of lighting quality. According to this definition, lighting quality exists when the luminous conditions are suitable for the needs of the people who will use the space. They grouped these needs in six categories: visual performance; post-visual performance (e.g., reading, eating, sewing, walking); social interaction and communication; mood state (happiness, alertness, satisfaction, preference); health and safety; and aesthetic judgments (assessments of the appearance of the space or the lighting) (5).

“lighting quality includes, in addition to visibility and visual comfort, consideration of the appearance of the space, energy efficiency, architectural integration and costs.” (4, p. 133).

Designers’ Lighting Quality (DLQ)
“Three local lighting designers were hired to form a panel to design nine different lighting systems for the office space. They were instructed to produce lighting designs that met current recommended illuminance levels for offices with VDTs, that met the three LPD levels, and that could currendy exist in open-plan offices in North America. The designers were free to develop their own definitions of low, medium, and high DLQ.” (5, p. 108).

“High-DLQ conditions would consist of indirect or direct/indirect lighting systems, all medium-DLQ conditions would consist of semi-specular parabolic-louvered recessed troffers, and all low-DLQ conditions would consist of recessed prismatic lensed troffers.” (ibid.).

Appearance of space/aesthetic impression
Aesthetic impressions—Judgments about the aesthetic appearance of the room were assessed using 27 semantic differential pairs (ibid.).

Luminance distribution
“All of the dependent variables were selected to provide measurements of concepts in a set of connected hypotheses about the effects of luminance distribution (created by varying the luminaires), non-task surface luminance (varied by changing the reflectance and colour of the cubicle surfaces)” (4, p. 133).

Non-task surface lighting

“Non-task surface luminance. Non-task surface luminance was varied by changing the fabric of the cubicle panels facing the occupant (behind the computer monitor). Five of the nine cubicles were grey with a reflectance of 0.30 (labelled light), and four were dark blue with a reflectance of 0.05 (labelled dark). This was the widest range of reflectances we could achieve with available materials.” (3, p. 194).

3.1.4. Operationalization

Veitch et al. and their studies of lighting distributions effect on several human health and wellbeing parameters, takes departure in a practice oriented operationalization. The theoretical ‘Lighting Quality’ are expanded and defined through the understanding and practice of professional lighting designers, to a more approachable concept: Designers Lighting Quality (DLQ). This operationalisation allows Veitch et al. to define conditions and design variables, that reflects real world lighting environments.

“Four different lighting installations were compared. The choice of lighting installations and their labelling was based on extensive advance consultation with lighting researchers, manufacturers, and designers as part of the project development process. All were designed to be representative of current office lighting practice in North America for a mid-level office.“ (3, p. 194).

3.1.5. Lighting Design

“The two experiments were designed to test a set of connected hypotheses about the effects of luminance distribution (created by varying the luminaires), non-task surface luminance (varied by changing the reflectance and colour of the cubicle surfaces) and control over lighting on various behavioural outcomes” (ibid.).

“High-DLQ conditions would consist of indirect or direct/indirect lighting systems, all medium-DLQ conditions would consist of semi-specular parabolic-louvered recessed troffers, and all low-DLQ conditions would consist of recessed prismatic lensed troffers.” (5, p. 108).

“Best Practice 1: The design team considered this the solution that would be the best practice for this type of office, providing a similar illuminance on the working plane as the Base Case 1 installation but brighter walls and ceiling and with reduced shadows and veiling reflections. The basic design solution was a suspended direct/indirect luminaire (Figure 3 and Table 3). Best Practice 1 with switching control. In this installation, the lighting of the hallway, conference room, and cubicle area was the same as in the Best Practice 1 lighting except that each cubicle was fitted with a free- standing desk lamp with a translucent shade (Figure 4 and Table 3), which the occupant was free to operate by changing the setting of the switch at any time. The lamp was set to 26 Wat the start of the day. Dimming control: This condition provided greater control over workstation lighting to the occupant, while maintaining adequate ambient illuminance. Each cubicle had centered over it a suspended direct/indirect luminaire (Figure 5 and Table 3). The indirect component (1 lamp) operated at a fixed level, and the occupant could change the level of the direct portion of the luminaire output at any time using an interface on the computer in the workstation. The initial level was set to 50%. Photometric conditions. Table 4 shows the mean illuminances provided by the four lighting installations on the work surface, on the monitor screen, on the keyboard, and at the participant's eyes, in the cubicles with the light and dark panels. Ranges (minimum to maximum) are provided for conditions with a degree of control." (3, p. 195).

"[…] there were recessed parabolic louvered luminaires (Base Case 1); suspended linear direct–indirect luminaires (at ?600 lx desktop illuminance) plus wall washing (Best Practice 1); suspended linear direct–indirect luminaires with a switchable desk lamp plus wall washing (Best Practice 1 with switching control); and, suspended workstation specific direct–indirect luminaires with individual workstation dimming for the direct portion plus wall washing (Dimming Control). Experiment 2 contrasted recessed prismatic lensed luminaires (Base Case 2) and suspended linear direct–indirect luminaires dimmed to 400 lx desktop illuminance plus wall washing (Best Practice 2)." (4, p. 135).

"Design 1 used recessed parabolic louvered 1 ft × 4 ft two-lamp luminaires in the ceiling. Design 2 used the same overhead luminaires as Design 1 and added a strip of one-lamp "partition washer" luminaires to increase the luminance of the panel directly behind the computer monitor. Design 3 used the same overhead luminaires as Design 1 and added a compact fluorescent angle-arm task light on the side desk. Design 4 lit the cubicle with one workstation-specific direct–indirect suspended luminaire with three lamps, one lamp providing indirect light by reflection from the ceiling and two lamps providing direct illumination to the work area; Design 4 also featured the same task light as Design 3." (2, p. 202).

3.1.6. Concluding remarks

In Veitch et al.'s first study in 1998, the results does not indicate any strong main effect of lighting distribution on health and wellbeing. Rather, moderating effects was found e.g. performance and satisfaction, and inetraction effects. These relationships are further explored in later studies, where 'Linked mechanism' theory is employed "The independent variables are valid instances of the constructs Designers' Lighting Quality and Lighting Power Density, but the luminous conditions change in several dimensions at once from one level of each variable to another." (5, p. 121).

Linked mechanism effect
"Overall, the results of the mediated regression analyses were strongest for the appraisal path, leading through preference and mood to health and well-being. The effects are strong, with explained variance as high as 56%. People who perceived their office lighting as being of higher quality rated the space as more attractive; as a result, they were in a more pleasurable mood; and, in turn, they reported less overall discomfort and greater satisfaction with the work environment and with their performance on that day. a mediated route from preference through motivation to task performance (Table 5).
[…]
The most consistent finding, and the one with the largest effect size, is the appraisal path. Overall, these experiments found that changing lighting installations influenced appraisals of lighting quality, and that people who were more satisfied with their lighting (regardless of the type of lighting they experienced) considered the space to be more attractive, were happier, and were more comfortable and more satisfied with their environment and their work." (4, p. 145).

General preference
Veitch et al. studies of lighting distribution and preference all points towards a preference of indirect-direct lighting design. This is widely supported by many other resembling studies, who refers to one

of the first researchers investigating this relationship: Hawkes R J, et al., (A note towards the understanding of lighting quality J . Illum. Eng, Soc. 8(2) 111-120 (1979)) – an article which despite attempts, couldn't be found. References to this article, highlights some of the results, that strongly indicates, that the general preference of lighting distribution is complex settings and variation in distribution over longer periods of time. This suggests that people prefer lighting environments that are visually stimulating in both distribution and contrast.

"Participants considered the direct/indirect systems to be more comfortable than the direct-only systems, with a further increase in comfort associated with individual control in Experiment 1. There were no simple main effects of lighting quality on the performance of any task, although the expected changes in performance associated with task visibility, practice, and fatigue were found" (3, p. 191).

Individual control – a bias

It is commonly agreed in many branches on environmental studies, that the ability to adjust own environment has strong effect on several wellbeing and performance parameters. Likewise, Veitch el al.'s studies report a consistent preference for individual control over the lighting environment.

"The beneficial effects of individual environmental control might not be through commonly understood personal control mechanisms as they relate to stressful situations (Averill, 1973). In the case of control over the physical environment, positive affect might be the mechanism." (2, p. 200).

For future studies, that include the possibility of adjusting/interacting with the lighting environment, a control setup should be included in order to differentiate between the positive effect of control and the possible positive effect of the light itself.

Variation in lighting conditions

Initially Veitch et al. uses very few lighting variations in the test setup. but finds in later studies, that a wider variation in lighting conditions provided better data:

"The most important of these is the wider variation in lighting conditions to which participants responded (16 combinations of lighting design and illuminance in the study vs. 4 and 2 in the data sets analyzed by Veitch et al., 2008). This could be expected to result in greater variability in the data and therefore less risk of restricted range"(2, p. 210).

Variance over time

In highlighted articles by Veitch et al. it is generally discussed, whether the short period of testing could have any limitations to the studies. As most subjects are tested in a matter of less than a day, the results reflect the more immediate reaction to the lighting. "Field investigation would also allow the accumulation of results over an extended period of time. Lighting conditions that can be ignored for one day might become more important when one is exposed to them for many days and months. Conversely, it may be that lighting conditions that are seen as better on first acquaintance become the norm over many months and so reduce in effect" (3, p. 217).

3.2. Kjell Y. Pedersen et al.

3.2.1. Problem

” It is a design issue in which management software, interface design, luminaire design, management infrastructure, architectural space design and user experiences form part of an overall interdisciplinary ecology of approaches. With an interdisciplinary approach, it is possible to investigate a complex problem area with different models, methods and tools that enable those involved to open up common or overlapping problems and seek knowledge across peers.” (6, p. 15, transl.).

3.2.2. Objective/hypothesis

Objectives
“[…] contribute to greater insight into which design issues adaptive lighting opens and especially how the integration of daylight and individual user wishes are promoted through different scenarios of adaptive lighting design.” (ibid., transl.).

Investigate a: “holistic balance between energy-optimization, wellbeing and architectural design that is experienced as meaningful in the everyday life.” (ibid., transl.).

”[…] explores how a co-ordination of lighting environments, user behaviour and management technology as dynamic elements can help provide increased room for manoeuvring the more functional and pragmatic management paradigms.”

Hypothesis:
well-considered and relevant use of energy resources can be better achieved by providing increased scope for individual solutions and continuous adaptation, with a broad sense of being able to shape their surroundings as needed. (ibid., p. 19, transl.).

Research question
"how to analyse and describe human activity as meaningful social events where, in addition to physics, presence and activity, context is included for the event (situation) and acknowledged that any moment in the daily flow of activities is different, but may be construed as a series of events (events)." (ibid., p. 81, transl.).

3.2.3. Terminology

The adaptive lighting
The adaptive light acts as an environmental effect, a quality of the dynamic light in the environment, best comparable to the fluctuating daylight of the way to present itself as complex. As an experience, the movement in the light is a combination of the light's own dynamics, the dynamic processes of perception, and the human's visual activities and movements in space. A central problem with the

adaptive light is to maintain the light experience as ambient, that is, as the environment's consistency, where it is maintained as a sustained part of the ambient character in the light. (ibid., p. 59).
"By the adaptive light, three active actions are clarified in our experience: our own actions, the actions of perception and the actions of light." (ibid., p. 62, transl.).

Areas of sustainability:

- Architectural design and building management
- life-practice and experience of users
- Intelligent and balanced consumption of energy resources

Ambiens
"In short, the ambiance, in the adaptive light of the EAL project, is the light situation that does not appear as something clearly illuminated or luminous, nor does it matter so much in the background that it becomes part of the general environment. The ambient light is apparent, it gives light and shape to the room and the ones present, but is not clearly distinguishable as single elements." (ibid., p. 18, transl.).

"Smidth's analyses of the ambiance of light (198-203) could work with the following range of concepts:

- Spatial signage - light sources form drafts and spatial shapes
- Enclosure - diffuse light material fills the room
- Dynamic projection - different intensities, colours, formations, volumes - are projected dynamically variable in space
- Zones of light - areas, geographies and priorities of zones and volumes in space
- Mediated effect - Medialization of light emphasizing relation to light sources and light path through reflections and shadows
- The person who sensed and sensed the centrepiece of the ambiance and who experiences the surrounding form" (ibid., transl.).

3.2.4. Operationalization

Through the framing of 'areas of sustainability', criteria can be developed and the potentials can be discovered: " The EAL project approaches this task by establishing the adaptive bargaining space (transl.: forhandlingsrummet) as conceptual design object, as "something" that conducts the coordination and negotiation of the adaptive dynamics, but where the actual implementation in lamps, control systems, the experience of light and architectural design is what the project tries to identify and realize concrete suggestions. […] strategies and software specification of adaptive lighting in the context of everyday situations, based on user-driven design implementations and software-specifications approached from a holistic IoT perspective." (ibid., p. 18, transl.).

Specifically, are the areas of sustainability 'architectural design' and 'experience of users' operationalized through the concept 'ambience' defined by Ulrik Smidth (7). The 'ambience' concept distinguishes between several layers of lighting, and takes departure in both perceived, experienced and sensed elements of lighting.

3.2.5. Lighting design

No concrete lighting design is suggested. Moreover, a general dynamic lighting concept and a tool is developed:

Dynamic lighting concept:
"The adaptive light is an adjustment of lighting, i.e. an exploitation of the possibilities of adjusting in the colour tone and light level of the light to suit the needs and requirements, but partly automated. It may be adaptation to usage patterns, work situations and general lighting requirements, as well as integration of artificial light to dynamically complement daylight variations." (ibid., p. 33, transl.).

Overall the general dynamic lighting concept:

- integrates user scenarios, daylight variations and architectural qualities in the design of light and control systems.
- dynamically regulates the intensity and colour composition of light with individual and place-specific solutions.
- daylight as a formative parameter
- adapts to the personal wishes and needs
- framework of architectural lighting design that considers the energy consumption.
- The key to optimal flexible light environments is: The adaptive light, unfolded as a system and implemented in buildings, will work better the more sensors and light sources that can be connected as independent elements.
- The adaptive dynamics are a service that coordinates needs and design decisions through software.
- It is assumed that coordinated and weighted design decisions could lead to better lighting conditions, better experience of light and, at the same time, result in less power consumption

In this sense, Pedersen et al. suggests a software solution, that integrates the complexity of a wide range of decisions, such as the overall framework for energy consumption, coordinated optimization strategies from building management, adjustments of daytime rhythms and ambient lighting conditions, customizable local needs tailored to establish appropriate workplace lighting and support local usage scenarios, and last but not least, the possibility to access individual control and aesthetic design solutions.

3.2.6. Concluding remarks

A general concept
Pedersen et al. does not conclude on any specific solution. The conclusion of the report is a very general concept that integrates a large number of potentials that are negotiated in order to produce the most suitable, sustainable and appreciated lighting environment. This unpreceded complexity is theoretically described by the individual potentials (see above section). The report suggests, that this concept and the complexity of potentials should be investigated through the many relationships, constellation and variables that the concept entails.

Need for complexity
Pedersen et al. acknowledges that dynamic lighting that considers practical issues, technical possibilities and especially human needs requires an acknowledgement of the need for complexity. Moreover, that these needs are more dependent on relationships than thresholds and absolute values (ibid., p. 19).

User control
The dynamic lighting concept developed by Pedersen et al. considers user control as a vital element of health, wellbeing but also sustainability: "The users becomes co-creators of their surroundings and lighting conditions. It requires a well-designed room for individual development of personal light design, and it is developed by organizing comfort parameters in a multi-dimensional and greater dynamic range for variation in design adaption." (ibid., p. 55, transl.).

No considerations have been made to the influence of the users e.g. how, when and I what degree, the users should be able to interact with the lighting system. The dynamic lighting concept developed by Pedersen et al. and the level of abstraction is open for interpretation in a very high degree.

3.3.Ulrika Wänström Lindh

W. Lindh has been working systematically and phenomenological with the experience of the distribution of lighting and visual spatial boundaries.

Articles:

I. (2010) Spatial Interpretations in Relation to Designer Intentions: A Combined Strategies Study in an Auditorium with Variable Lighting (unpublished article)
II. (2010) Ph.D. thesis: 'Light Shapes Spaces Experiences of Distribution of Light and Visual Spatial Boundaries'
III. (2013) Distribution of light and atmosphere in an urban environment (unpublished article)
IV. Understanding the Space: How Distribution of Light Influences Spatiality (unpublished article)

3.3.1. Problems
"Most of the existing lighting research focuses on illuminance and colour tem- perature while there have been few studies of the relationship of the distribu- tion of light and spatial perception. Distribution of light is difficult to measure and better suited for visual evaluation, and is therefore possibly not as well researched." (8, p. 21).

3.3.2. Objectives/hypothesis
"There is a relationship between a clearly delimited and a tangible space. As a consequence, a room without illuminated walls is less spatially enclosed than a room with illuminated walls. Illumi- nated walls contribute to creating a more delimited space that is easier to grasp. Furthermore, a light zone can appear as "the space", which sometimes is more important than the physical space. Nevertheless, one wonders in what situations this hypothesis of illuminated walls becomes evident, since it is related to the context and the whole situation of contrasts." (ibid., p. 29).

3.3.3. Terminology

Spatial distribution
"In this text, the concept of spatial distribution of light is defined as a visually perceived distribution of light in a space, such as the complex inter- action between several light sources (including daylight and electric light) and reflections from surfaces that can be observed visually as differences in lightness and brightness with respect to light patterns and light directions in an entire space. (ibid., p. 22).

Light topography
"The light topography is linked to hierarchies that emphasise a private or a public atmosphere impression. Hierarchies of light can be found indoors (Millet, 1996, p. 117) as well as outdoors. We can observe that different road users and speed restrictions also correspond to different heights of luminaire placements and also by the distance between luminaires. Urban light has a scale comparable to the musical scale, yet the height the light is placed at is relative, relating to functionality, environmental scale and economy." (ibid., p. 65)
"The concept of light topography should be further developed and used as a tool for rhythm and atmosphere analysis. The assumption that inward-directed light increases the feeling of being safe in some spatial contexts, while outward-directed light can probably increase reassurances of safety in other contexts, such as with varying vegetation and different luminaire height, needs to be further studied." (ibid., p. 131).

Spatial experience
"The concept of perception is used to describe how we see and directly apprehend and understand spaces' size, shape, depth and distance. It also addresses experiences such as the level of light and the level of colour as perceived qualities. Spatial experience includes perception, though also a wider range of interpretations. It is an indirect level of understanding. When describing the experience of being inside a tangible space, it deals more with experience than perception, since feelings are included. Furthermore, it refers to what makes a room's atmosphere seems warm, enclosed, how intense the light contrast is and if the light patterns seem to be active or calm. Even though previous research has shown that it is possible find agreement in the experience and impression of illuminated space (Boyce, 1981, p. 271), all of our perceptions and experiences are still culture dependent. Spatial experience comprises several sub-categories: a) issues related to space as in spatiality and b) spatial enclosure, the quality of being surrounded by spatial boundaries, as in the case of vertical walls in a space, and c) the experience of a tangible, clearly defined space. Spatial enclosure does not only deal with where the borders of the space are located and how distinctly these limitations are experienced. It also refers to the experience of a spatial extension and the feeling of being surrounded, like being inside a spatial unit." (ibid., p. 58).

3.3.4. Operationalization

Through a departure in the concept 'Experienced space' that addresses how the borders of light and space are experiences and how the mutual influences, Lindh allows a geometrical approach to investigate distribution of lighting and the influence of human perception/experience:

Experienced space
The experienced space has an experienced extension in all directions (depth, width and height) while the physical space has a measurable extension. Sometimes they coincide. It also has the ability to

express spatial characters (closedness–openness) as well as atmosphere and mood. There are two possibilities with experiencing illuminated spaces:

a. The borders of the experienced space can coincide with the physical space, and the experience of both can be changed by the light.
b. Light can constitute experienced spatial units that do not coincide with the physical space

Light influences these experienced spaces (in both cases) by characteristics such as the:

- perceived level of light
- perceived spatial distribution of light
- perceived lightness and brightness contrasts
- interplay between lighting and inherent surface colours
- emphasis of highlighted objects or surfaces

3.3.5. Lighting design

Through the departure in the borders of space versus the borders of lighting, several experiments are designed and performed to systematically test e.g. heights, rhythm and constellations of lighting points.

“The way in which distribution of light impacts spatial enclosure was shown by analysing light zones and wall emphasis. Size and shape are affected by patterns of light and the direction of light. Atmosphere – specifically, effect on attention and feeling of safety – was shown to be affected by the distribution of light. The profession of an observer was shown to affect the interpretation of these questions, specifically with respect to different possible understandings of spatial concepts.” (ibid., p. 126).

3.3.6. Concluding remarks

Findings
“The findings of these studies lead to a discussion of when, why and how patterns of brightness and darkness influence spatial perceptions of dimensions. The findings also show that brightness not only contributes to our experiencing a space as more spacious than it really is, but in certain situations brightness can actually have the reverse effect. Furthermore, darkness can contribute to a spacious impression, which has hardly been discussed in previous research. What subjects regard as a space may shift between the clearly defined physical space and the perceived space, which include light zones. […] Light zones can create a sense of inclusion or exclusion for subjects, which affects their sense of community and their feeling of safety. […] topography, e.g. the height of luminaire positions, as well as light direction influence the way we experience the private and the public.” (ibid., p. Abstract).

Geometrical approach
The geometrical approach allows Lindh to systematically test distribution variables (such as height, width and depth) and concludes:
“A conclusion to draw from the studies was that distribution of light indeed is an effective tool; a single variable such as luminaire positions in the ceiling can cause large changes in perceived spatiality. The spatial context and subjects’ varying interpretations were shown to give rise to

contradictory findings. In these studies it was found that it is not only brightness that can have an enlarging effect, but darkness can also increase spaciousness, and brightness can also decrease spaciousness. Comparing findings from these three studies lead to the hypothesis that brightness often increases spaciousness up to a certain level of light, but when spatial surfaces become too bright and prominent the effect can be reversed. In these studies it was found that light zones can contribute to an inclusive or excluding atmosphere. A focused light in darker surrounding called for attention, reduced interviewees' speaking volume and made them more attentive to sounds. These studies also show that distribution of light can impact colour impressions in a space." (ibid., p.127). These interesting findings from a number of explorative and qualitative experiments, offers great potentials for further and more quantitative investigations in terms of more established parameters for e.g. health and wellbeing. More research is needed to establish the potentials of lighting distribution, but Lindh's studies clarifies the significance and importance the distribution of lighting.

Uniformity

Like previous mentioned studies by Hawkes and Veitch, findings from Lindh's studies also suggests, that the propagation of 'uniform lighting' is misunderstood, and preference and positive effects are linked to more uniform lighting: "[…] in particular the importance of light on vertical surfaces for the experience of spatial enclosure, and the light topography, e.g. the height of luminaire placements, this emphasises the need for a research and a light planning that privileges non-uniformity and that uses visual observations in real, complex spaces." (ibid., p. 128).

Explorative qualitative methods

it is worth emphasizing that the explorative and qualitative method contributes to producing rich data that can help create new theories for further studies - where quantitative methods may be more restrictive and require many iterations - such as the studies by Veitch et al. that several laborious experiments before she comes up with a hypothesis that partially can be confirmed.

"Even though several new findings came out of this thesis, the largest contribution is most likely that it shows how methods with an artistic qualitative approach, maybe seen as "inconvenient", can lead to rich, new findings. Through this, several established research findings were questioned and new theories were developed." (ibid., p. 129).

3.4. M. Stokkermans

3.4.1. Problems

"With this growing potential and complexity of lighting systems comes a growing need to deepen our understanding of how light designs translate into the ultimate experience of a space. This includes insight into three important types of relationships: (1) the relation between the control parameters of a lighting system and the resulting spatial distribution of light in a space, (2) the relation between the distribution of light and how that light is perceived in terms of attributes such as brightness and uniformity, and (3) the relation between the perceived attributes and the impression of a space." (8, p. 1).

3.4.2. Objective/hypothesis

Hypothesis

"The impression of a space depends hugely on the light in the space, more specifically on the intensity, colour, beam shape and position of the light sources in that space. This relation though is very complex. The present study aims at understanding the relation between parameters of a lighting design and the resulting perceptions, focusing on the effect that overall brightness and perceived uniformity of the light in the space have on the perceived atmosphere of that space." (ibid.).

Objective
"The main aim of the current study is to investigate how the brightness and perceived uniformity of the light in a room affects the atmosphere dimensions. Additionally, previously reported objective measures to quantify the brightness and perceived uniformity of the light are evaluated. As the conditions in the present study only consist of overhead light, the dimension peripheral – overhead is not considered." (ibid., p. 2).

3.4.3. Terminology

Perceived uniformity / non-uniformity
"Hawkes et al. found that two dimensions are required to describe the perception of light in a space, namely brightness and interest, where the first is related to the perceived intensity of the light and the latter to the perceived uniformity. Research by Flynn et al.1 similarly revealed the dimensions dim – bright and uniform – non-uniform as relevant for characterising the perceived light in a space" (ibid., p. 2).

3.4.4. Operationalization

First and foremost, Stokkermans et al. builds on past studies of lighting distribution by Hawkes et al., moreover they limit the scope of variables, and thereby the variations in lighting conditions tested: "The light conditions varied in three ways: (1) by the number and spatial distribution of the luminaires in the ceiling, (2) by the type of luminaires and (3) by the luminance of the light design. These light conditions served as a way to study the effect of perceptual light attributes and not to study the effect of the design parameters per se." (ibid., p. 3).

3.4.5. Lighting design

"We used perceptually-accurate, 3D, computer-generated visualisations of a space, presented on a calibrated display, allowed us to present more than 100 conditions in a fully randomised order, This study used a five (luminance) by seven (spatial distribution of luminaires) by three (type of luminaire) full-factorial within-sub- jects design. The independent variable luminance consisted of five light levels. The spatial distribution of luminaires comprised seven levels, varying in the number and position of the luminaires. Lastly, the type of luminaire consisted of three levels, namely halogen luminaires emitting directional light with a full width half maximum (FWHM) beam angle of either 248 or 128, and fluorescent luminaires emitting diffuse light. All independent variables were assessed in a random order." (ibid.).

3.4.6. Concluding remarks

Context, space and furniture
"Results may be different for spaces in different contexts, of different shapes and sizes, or for different types and arrangements of luminaires. Our assumption is that the insights on the relationship between perceptual attributes and atmosphere perception will prove more consistent and generalizable across situations. In order to confirm this assumption, more research is required to understand effects of light on atmosphere perception beyond the range of our manipulations, for spaces of different shapes and

sizes. Additionally, future research may address the effects of more furniture in the space, to increase our understanding how furniture influences the effect of the light on atmosphere." (ibid., p. 14).

Method and approach
Stokkermans et al. are concerned with understanding how a number of parameters of LED-based light systems may influence the perceived atmosphere of an environment. Unlike Lidhs and Pedersen's theoretical, explorative, qualitative and holistic studies, Stokkermans are more quantitative, mathematical and reductioning: "We have found that the dimensions of atmosphere can be accurately described by a second-order polynomial as a function of the two perceptual light attributes. Although these relations are complex, Figure 4 depicts them in a very apparent way. In order to create a dedicated atmosphere, the perceptual light attributes also have to be specified in terms of the physical spatial distribution of light in a space. However, the objective measures for brightness and perceived uniformity reported in literature did not result in adequate predictions of these perceptual attributes for our light conditions. Therefore, future research should concentrate on improving these measures. Nevertheless, this study is an important first step towards understanding how the numerous control" (ibid.).

3.5. David Loe et al.

Articles:

I. 1994 Appearance of lit environment and its relevance in lighting design: Experimental study
II. 2000 A step in quantifying the appearance of a lit scene

3.5.1. Problem
"The purpose of this project was to examine the relationship between a subjective response to a lit environment and its luminance distribution as a contribution to improving lighting design." (9, p. 119).

3.5.2. Objective /hypothesis
"Most interior lighting installations are designed on the basis of task illuminance together with a possible consideration of discomfort glare, and yet the way a space is lit will have a major influence on its appearance and visual appeal. However, despite its clear importance, this aspect is rarely considered by most lighting designers." (ibid.).

3.5.3. Terminology
Visual interest
"The 'bright' installations were those that contained lit surfaces within the normal field of view and the most 'interesting' installations were those that contained areas of light and shade." (ibid.).
"The observers also liked a space to appear 'interesting' which related to a degree of non-uniformity of the light pattern. Flynn's work also showed how people's behaviour could be affected by the way a room is lit. This was demonstrated by a study that made use of a cafeteria: in this it was shown that the way the room was lit could affect the place where people sat and the direction they faced. Generally, people liked to face a bright surface, in this case a lit wall." (ibid.).

3.5.4. Operationalization
Loe et al does not employ specific methods or approaches in the highlighted studies of ‘appearance of lit space’. Rather, a location is used as a point of departure: “The experimental room at The Bartlett is situated within an existing room space. Figure 3 gives a plan and other details of the room and for this work it was furnished as a small conference room. It could be lit in a variety of ways from a range of lighting equipment: in this study, the lighting comprised three main groups referred to as Experiments I, II and III, each group consisting of six different lighting patterns.” (ibid., p. 120).

3.5.5. Lighting design
“Full-scale mock-up conference room lit in 18 different ways. 18 different lighting schemes were devised: although different in appearance, each provided an illuminance between 400 lux and 500 lux on the desk surface, and none of the installations produced lighting that could be judged as uncomfortable.

- Experiment I employed ’uniform’ lighting provided solely by two banks of vertically-mounted tubular fluorescent lamps viewing position, but out of sight of the observer. The lamps (Philips 1500 mm 65 W Colour 84) placed either side of the were controlled by dimmers and so, by a combination of switching and dimming, a range of average luminances was conditions (A-F) were used.
- Experiment II (U-Z) ranged from the ‘uniform’ as used in Experiment I, through different degrees of uniformity of light pattern provided by various luminaire arrangements, to ’concentrated’ lighting directed on to the table using luminaires with opaque shades mounted 720 mm above the table.
- Experiment III (M, N, P-S) used the ’concentrated’ light pattern of Experiment II as a base. The degree of concentration within the whole field of view was varied by the addition of other luminaire arrange- ments. The horizontal illuminance at the centre of the table for all the conditions in Experiments II and III was adjusted to 300 lux.” (ibid., p. 119).

3.5.6. Concluding remarks

Visual interest and visual lightness
“Observer subjective assessments were examined using factor analysis and this identified two main factors: ’visual interest’ and ’visual lightness’. The experiment showed that these two factors could respectively be described by the luminance contrast and the average luminance within a horizontal band 40° wide and centred at normal eye height. The results suggest minimum values for these two parameters which are likely to be necessary for a lit environment to appear both ’interesting’ and ’light’” (ibid., p. 127).
“We only have a relatively simplistic knowledge of appearance lighting criteria. The important result from this work is that people require from their lighting not only good, comfortable task lighting conditions, but a lit environment that is apparently ’light’ and one that is ‘visually interesting’. (ibid., p. 128).

Lighting composition
“What the lighting designer should understand from this, is that lighting needs to be a composition of light and shade put together in such a way that it complements the architecture in an holistic way, and in doing this provides a lit environment that is both light and interesting.” (ibid.).

Measurements
"With regard to the physical measurements, the experiment showed that the two subjective parameters of 'visual lightness' and 'visual interest' related very well to the lighting within a horizontal band 40° wide and centred at normal eye height." (ibid.)

Uniformity vs. non-uniformity
"[…] the installations which are judged to be the 'most interesting' are those which comprise more than one lighting system, e.g. spotlights and over-table lighting (P), spotlights and uplighting (Y) and wall-washing and over-table lighting (R), whereas those installations which are judged to be the 'least interesting' are those having a uniform pattern of light and particularly those which have a low light level as well." (ibid., p. 123)

Discussion

Operationalisation
The distribution of lighting is a neglected area within lighting research. Consequently, we have no methods nor metrics to assess the distribution of lighting. The few researchers that addresses distribution of lighting and has been highlighted in this working paper, they have all to some extend constructed a conceptual framework in order to operationalize 'light distribution' and hence, make it assessable to systematic studies. These operationalisations varies greatly:

1. Practice-based operationalization (Veitch el al.)
2. Geometry-based operationalization (Lindh)
3. Aesthetic philosophical -based operationalization (Pedersen et al.)
4. Location -based operationalization (Loe et al.)
5. Operationalization based on established variables (Stokkermans et al.)

User control
Many of the researchers highlighted in this working paper are addressing the elements of user control. Especially those concerned with uncovering preference and appreciation or who simply just employ a more user-centric approach. It is suggested, that user control is important element to both health and wellbeing and sustainability. Future research that includes user control as an element of the dynamic lighting design system, should take into account, that user control has a positive effect in itself, and should therefore be separated from the effect of lighting itself.

Uniformity
Several of the studies highlighted in this working paper points towards the importance of considering non-uniform lighting, and comments on the misunderstanding of uniform lighting as ideal or standard. This might be one of the strongest argument for investigating the distribution of lighting and its effect on perception, experience, health, wellbeing, performance etc. – evidence show, that non-uniform lighting is preferred. Non-uniformity put significance on the distribution of lighting. So future studies, should continue on these studies, in order to produce evidence for how distribution of interesting, stimulating and inspiring lighting environments can be addressed, tested and designed.

Literature

1. Greenhalgh T, Peacock R. Effectiveness and efficiency of search methods in systematic reviews of complex evidence: Audit of primary sources. Br Med J. 2005;331(7524):1064–5.
2. Veitch JA, Stokkermans MGM, Newsham GR. Linking Lighting Appraisals to Work Behaviors. Environ Behav. 2013;45(2):198–214.
3. Boyce PR, Veitch J, Newsham GR, Jones CC, Heerwagen J, Myer M, et al. Lighting quality and office work: two field simulation experiments. Light Res Technol. 2006;38(3):191–223.
4. Veitch JA, Newsham GR, Boyce PR, Jones CC. Lighting appraisal, well-being and performance in open-plan offices: A linked mechanisms approach. Light Res Technol. 2007;40(2):133–48.
5. Veitch JA, Newsham GR, Boyce P, McGowan T, Loe D. Lighting Quality and Energy-Efficiency Effects on Task Performance, Mood, Health, Satisfaction, and Comfort. Discussion. Authors'reply. J Illum Eng Soc. 1998;27(1):107–29.
6. Yngve Petersen K, Søndergaard K, Kristensen O, Augustesen C, Rask N. Energioptimering gennem adaptiv lysstyring. 2017.
7. Schmidt U. Det ambiente : Sansning, medialisering, omgivelse. Aarhus Universitetsforlag; 2013.
8. Stokkermans M, Vogels I, de Kort Y, Heynderickx I. Relation between the perceived atmosphere of a lit environment and perceptual attributes of light. Light Res Technol. 2017;147715351772238.
9. Loe L, Mansfield KP, Rowlands E. Appearance of lit environment and its relevance in lighting design: Experimental study. Light Res Technol. 1994;26(3):119–33.